Unmanned Research Raft
Final Design Review Report

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Presented by Sea Cubed:
Jacob Davis – jdavis90@calpoly.edu
Andrew Fleming – aflemi04@calpoly.edu
Luke Vickerman – lvickerm@calpoly.edu
Kahye Yu – kyu30@calpoly.edu

Sponsor:
Paul Nyholm
Sam Fuller
Lawrence Livermore National Labs

Statement of Disclaimer

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Abstract

This document serves as the Final Design Review report for the design team conducting the research raft design project for Lawrence Livermore National Lab (LLNL). Our team has taken on a project to design a new research raft for LLNL.

The current rafts are suitable, but engineers have modified and altered the rafts to add more features as needed. This has led to a raft that accomplishes mission goals, but still has room for streamlining. The battery technology has also improved. Our goals were to redesign the raft from the ground up, reducing the size and weight. We also wanted to incorporate some new method to increase raft density in the designated storage space.

We underwent extensive customer and background research to begin the ideation design process with the goal of deciding a final design direction. After multiple phases of idea generation and refinement, we agreed on a stackable catamaran raft design with inflatable pontoons. Drawing from preliminary design evaluations, we felt confident that this initial design direction meets all our engineering specifications. After receiving approval and feedback from our sponsor, we began detailed design to work towards manufacturing a verification prototype.

Our detailed design efforts led to a final design for the entire raft. Because of the expense of some components of the final design, we made modifications to manufacture a verification prototype with the resources we had and at a lower cost. These modifications included reducing the total amount of welding necessary for the frame and substituting expensive purchased components with cheaper options. We used the Cal Poly Machine Shops to manufacture the entire frame, and upon completion the raft was assembled.

During and after assembly, we subjected the verification prototype to a variety of tests, to ensure the design met the previously defined engineering specifications. The tests included a raft assembly and deployment time test, a payload box waterproofing test, and an on-water speed test. The prototype passed most of these tests, and where it failed, we made some changes to ensure the integrity of the design. While ensuring that the design meets the specifications, the testing also provided insight into how and where the design could be improved.

At the completion of the project, we shipped the raft and all its components to LLNL. It is our hope that they first use it as a first iteration, to improve portions of the design, and then to implement the design for their entire fleet of rafts. While this may take some time and capital investment to accomplish, we feel that our efforts have the potential to radically change Lawrence Livermore's testing capabilities.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

This section will outline the problem proposal, the design team, and the sections of this report.

Lawrence Livermore National Laboratory (LLNL) is a federal research facility that operates a fleet of autonomous research rafts carrying scientific instrumentation to capture data in the ocean. LLNL's current research rafts are heavy, have a large footprint, and are difficult to transport. Paul Nyholm, an engineer at LLNL, would like our team to design a new research raft that weighs less, has a smaller footprint, and is easily transportable [1]. Mr. Nyholm introduced Sam Fuller, an engineer at LLNL, into the project, to serve as a second advisor and stakeholder.

The current design challenge is a transition from the problem as proposed. Mr. Nyholm was initially looking for a test platform for motor configurations. LLNL wants to improve the maneuverability of their rafts and is currently undergoing design revisions to implement an improved motor system. The initial project proposal was to design the test platform on which to try these configurations. Following conversations with our project team, we reached a consensus that we would pursue a design direction that would allow for more creative problem-solving. Mr. Nyholm agreed, and proposed that the team redesign the current rafts instead of attempting to repurpose the current raft as a testing platform. While this proposal is a slightly larger endeavor, we have embraced this new design direction.

Our senior design team consists of four members: Jacob Davis, Andrew Fleming, Luke Vickerman, and Kahye Yu. We are a group of mechanical engineering students tasked with this yearlong senior design project as a capstone to our undergraduate curriculum.

This Final Design Review Report documents the initial concept stages of the engineering design process for this project, as well as the previous Scope of Work. The main sections of the report include Background, Objectives, Initial Concept Design, Final Design, Manufacturing, Design Verification, Project Management, and Conclusion and Recommendations. In the Background section, we conduct product and technical research to help identify areas of weakness on current designs, and to investigate how we could improve on them for our design. The Objective section outlines the design problem and design specifications, as expressed by our sponsor. The Initial Concept Design section describes the process of choosing the initial design concept, specifically the controlled convergence process and its results, the preliminary analysis of the chosen concept, and challenges that the team may face. Final Design takes the components from the Concept Design chapter and explains the ways in which we have refined and justified their use. This section includes the structural prototype and the justification for our design decisions. The Manufacturing section details the methods by which we manufactured the verification prototype, referencing appendices for the detailed drawings and initial manufacturing plan. This section also includes our assembly procedure. The Design Verification section outlines how we tested our prototype, verifying that it functions and meets the engineering specifications. It also includes recommendations for future testing, to both this version of the design, and any future version of the design. The Project Management section explains the timeline and deliverables for the project; specifically, it covers the tools we used over the course of the project, and what methods for project management we would continue to use for future projects. Finally, the Conclusion and Recommendations section provides our concluding thoughts on the project, and what we suggest as next steps for the design.

2.0 Background

Preliminary background research focused on collecting data on the existing raft, investigating other existing autonomous ocean vessels, and researching key components for design use. We collected information on the current raft model used at LLNL through multiple interviews with Mr. Nyholm, who provided videos, pictures, and specifications to enhance our understanding of the current raft and problems facing LLNL. Existing product research involved analyzing autonomous research vessels used for a wide variety of applications. LLNL uses a vessel tailored to the specific needs of their work, seen in Figure 1. We kept competition product research broad to ensure there was enough background to support new design ideation. The technical research provided insight into the science behind various structural components including hull design and stability. Initial component research concentrated around major structural and mechanical aspects we believed would be influential in ideation and we continued this research throughout our ideation and prototype process.

2.1 Stakeholder Research

The research raft currently in use at LLNL utilizes a catamaran design with a custom frame to accommodate research payloads and motor mounting. It uses large rubber pontoons and four motors mounted in pairs on the left and right side of the waterproof electronics box. The current raft has a large, heavy, and robust physical design. Crew members launch and retrieve this raft from a larger vessel that transports them out to the test location. LLNL equips the current rafts with cameras and hydrophones for data collection and uses a printed circuit board to control the motion of the raft. The current construction is effective in some circumstances where the payload is large, but often the payload is smaller, and a large vessel becomes inefficient. [1]

Figure 1. The existing LLNL research raft. [1]

Our interviews indicated that there are some effective elements on the current research raft, including:

1) The raft's large physical size, which creates a stable flotation platform in rough seas and the ability to support a high load capacity.
2) Most the craft's weight is relatively close to the water which minimizes the instability effects induced from the 7-foot-tall light pole.

Despite these advantages, there are complications with the rafts, including:

1) The limited craft maneuverability, due to the motor positioning and overall weight.
2) A limitation on the number of rafts that a crew can take on a mission, due to the conflict between restricted deck space on the ships that deploy the rafts and the current large raft footprint.
3) Requiring several workers and heavy machinery to move the rafts around the ship and in long-term storage, as well as when collecting them from the ocean.
4) A long lead time and logistic difficulties before the start of a mission to pack, transport, and unpack the rafts from the shipping containers used during the several months of ocean transit.

We determined a list of the preliminary needs and wants for the new design, from these interviews. Meeting these will help reduce the conflicts presented in the current model. They include:

1) a smaller deck space footprint or the ability to stack,
2) a reduction in the overall weight,
3) a size that is shippable by air in a standard crate,
4) a stable design in three-to-five-foot waves, and
5) the ability to support a small payload of data collection devices.

2.2 Existing Product Research

LLNL uses customized rafts to meet the specific testing and studies that they perform out in the field. An exact product – one that encompasses all LLNL wants and needs – does not currently exist, but there are various other nautical research crafts that achieve elements that meet the general needs and wants provided in the existing product research. We have listed competition products here and highlighted elements that currently address some portion of desired final product.

1) Liquid Robotics Wave Glider

The Liquid Robotics Wave Glider is a very durable and light weight research craft powered by wave and solar energy. It has GPS-based navigation and data communication through satellite and cellular connection. There is space within the hull to house 7 payloads, but they need to be relatively small [2]. The compact design allows ease of transportation and field use, but size limitations and limited control make it impractical for LLNL’s purposes. Figure 2 presents the wave glider in use.

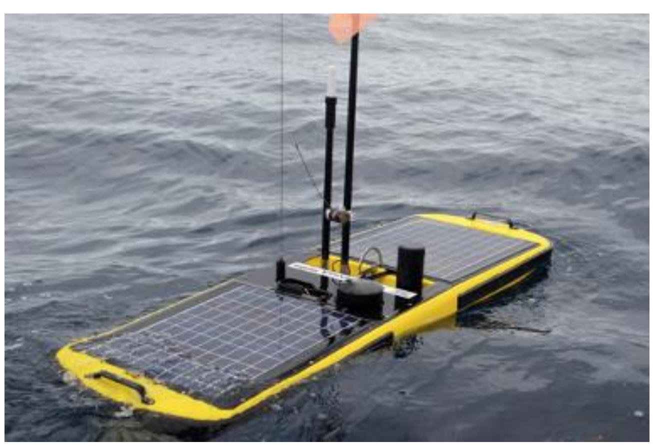


Figure 2. Liquid Robotics Wave Glider in the ocean. [3]

2) Over-the-Horizon Buoy

The United States Navy uses the Over-the-Horizon (OTH) portable impact locations system (PILS) to record missile testing data. The OTH PILS buoy allows for data collection near the impact while the Navy ship can stay 25 miles away in the safe zone. GPS receivers built into the buoy control positioning near the testing site and a satellite signal enables communication of vitals to operators. The crew must extract the data collected during the test after they retrieve the buoy from the test site. The physical design is compact due to the small payload. The buoy utilizes sound to locate the exact location of missile impact and does not travel very far, eliminating the need for large battery capacities and complex motor function [4]. This design meets various features desired in a new craft design, but this limits the buoy to a small payload and minimal versatility. Figure 3 shows the OTH PILS-2 buoy and the original OTH prototype.

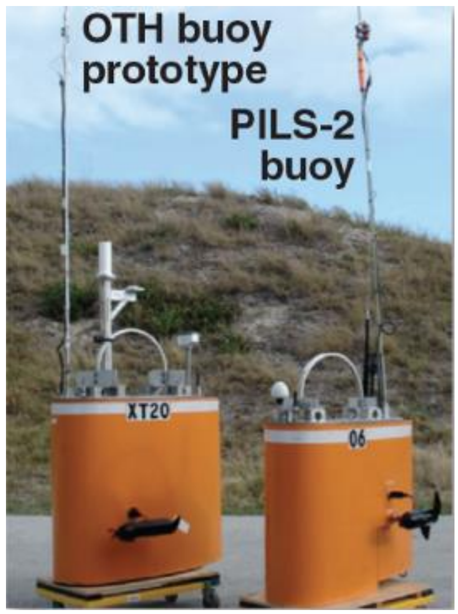


Figure 3. Over-the-Horizon PILS-2 buoy and prototype. [4]

3) Florida Department of Transportation Bridge Inspector Craft

Florida Atlantic University (FAU) developed an unmanned, over-the-surface, marine vehicle to provide support to the Florida Department of Transportation (FDOT) in the inspection and maintenance of Florida’s 11,450 bridges. These vehicles help study the condition of bridges in splash zones where the buildup of corrosive salt can cause bridges to become unsafe and unusable. The vehicles have various configurations to accommodate different data collection processes. Initial configurations put an emphasis on above and below water photography. The vessel floats on two pontoons and an operator controls the vessel through GPS. Having two motors allows it to hold position and move effectively in confined spaces and under bridges [5]. The large footprint and high center of mass may provide challenges for LLNL's use in the ocean, but the integration of various payloads and efficient travel are relevant to the new design. Figure 4 displays the inspector craft in the field and provides reference for the frame and pontoon construction.

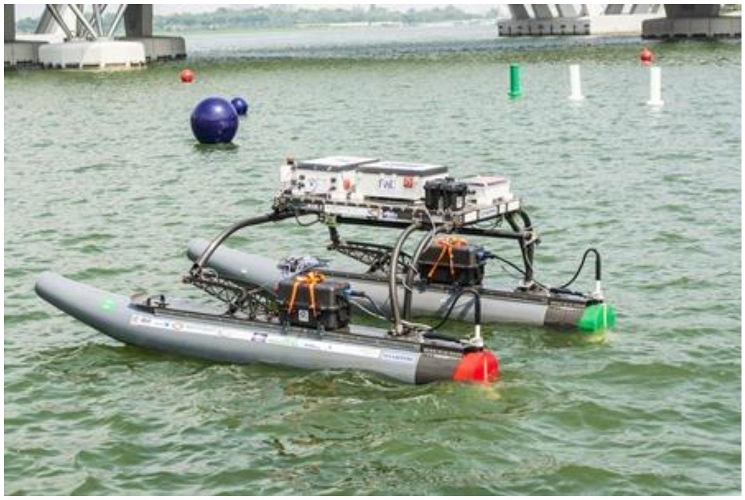


Figure 4. FDOT over-the-surface bridge inspector craft. [6]

4) Angus Adventures Autonomous Solar Boat

Angus Adventures is a start-up that is designing a variety of solar autonomous ocean research vessels. They developed a trimaran design with the goals of increased reliability, speed, and stability [7]. They chose a trimaran configuration because it allows them to streamline the hull shape while still providing deck space for an array of solar panels. The drive system consists of an inboard brushless electric motor magnetically coupled to the propeller drive shaft. Figure 5 shows a prototype of the solar boat without the solar panels. This design is of interest primarily for its stable, yet lightweight and streamlined hull configuration.

Figure 5. Prototype for Angus Adventures Autonomous Solar Boat. [7]

5) Seafloor Systems EchoBoat-240

The EchoBoat-240 is a surface vehicle developed by Seafloor with data collection capabilities in freshwater applications. The construction is relatively compact; with a length of less than ten feet, it still accommodates multiple payloads. Control of the boat is either both manual or autonomous, and two 800 W thrusters propel the craft. With upgraded hardware, the vessel has the capabilities of a 1.25-mile range and 6-hour battery life at nominal power. Data collection devices are onboard the craft and communication is accomplished through radio connection [8]. The control and range that this vessel accomplished meets the desired requirements for the intended final design but the lack of transportability and durability in rough seas void its practical use for LLNL. The EchoBoat-240 is the most similar model to the existing raft that LLNL uses but Seafloor has a full line up of different models ranging in size and capabilities. Figure 6 depicts the EchoBoat-240 model.

Figure 6. Seafloor Systems EchoBoat-240 model in use. [8]

6) MarkSetBot

The MarkSetBot is a GPS controlled autonomous marker for sailboat racecourses. The craft is fully inflatable and weighs 115 pounds in total, making it easy to transport and deploy. Race coordinators can set race marker coordinates on an app and the craft will travel to a location and maintain position. The craft has a 7’x7’ footprint size and can operate in up to 30 knot winds and 8 to 10ft waves. According to the company website, the craft has a 100 Ah battery that can last for 20 to 24 hours in winds of 8 to 10 knots and moderate chop. [9]

Figure 7. MarkSetBot in use during a race (left) and a Prototype MarkSetBot (right). [9]

Table 1 summarizes the strengths of these existing products and highlights the aspects of the designs we can improve upon.

Table 1. Summary of Current Product Strengths and Weaknesses.

Product Name	Product Strengths	Product Weaknesses
Liquid Robotics Wave Glider	Durable Lightweight Easily deployed	Limited payload space Limited maneuverability
Over-the-Horizon Buoy	Compact Long-distance communication	Limited range Limited payload space
FDOT Bridge Inspector Craft	Modular Effective movement	Large footprint Potential for instability
Angus Adventures Solar Boat	Streamlined Stable	Limited to no payload space
Seafloor Systems EchoBoat	Long range Effective craft control Compact	Not transportable Lack of durability
MarkSetBot	Lightweight Inflatable Stable	Limited Payload capacity Short battery life

2.3 Report, Article, and Journal Research

To better understand the knowledge base surrounding watercraft on the scale that we plan to provide, we investigated technical reports, engineering journals, and general articles on topic we felt would be pertinent to our design process. Listed here is a selection of those findings.

1) **Autonomous Boat for Invasive Aquatic Plant Species Management**
   This report describes the design of an autonomous boat for a specific application, including hull shape, fabrication, propulsion, and control [10]. Many design specifics described in the report are not useful to us because they pertain to the use of this boat, but the design processes and design features described can serve as inspiration for our ideation. Figure 8 shows the prototype boat.

Figure 8. Prototype Invasive Species Management Boat. [10]

2) **Autonomous Surface Vehicle for Geological and Geophysical Surveys**
   This report describes the design process for autonomous surface vehicle, with an emphasis on the design of the hulls. The report covers how they chose a hull type and the analysis performed to optimize the hulls for low hydrodynamic drag. [11]

3) **Vessel Stability Guide**
   This report by the US Coast Guard provides an overview of vessel stability and serves as a basics guide for captains and crew of fishing vessels. It explains concepts like center of gravity, buoyancy, and righting moments. It also describes the effect of high winds and seas on vessel stability [12]. Although the report is most applicable to monohull vessels, the physical forces involved will still be present on a multihulled craft. This report will be useful for evaluating the stability of raft design in future concepts.

4) **An analysis of variable dissolution rates of sacrificial zinc anodes**
   Corrosion is a huge issue on any type of metal component found in the water, specifically on boats, pipelines, and turbines. Often, to slow down the effects of corrosion, a sacrificial anode is added to these components. Sacrificial anodes are highly active metals used to prevent less-active metals from corroding, in a process called cathodic protection. On seawater boats, zinc anodes are common and maintenance teams can change them annually [13]. This article may be helpful when we consider the effects of corrosion on our research craft.

5) **High Stability and Low Drag Boat Hull**
   Chris Rickborn created a modified V-hull design that achieved proper planning at desired speeds while maintaining proper stability and buoyancy. In his background work, Rickborn summarizes the effects of varying hull designs of boats on fuel economy, maneuverability, and stability; the article provides insight on different styles of hulls and their advantages and disadvantages. The different hull styles mentioned are flat bottom hulls, v-bottom hulls, and rounded hulls [14]. This article will provide insight for our design when we consider the required speed and stability of our solution.

2.4 Propulsion Method Research

Since it would be outside of the scope and requirements of the project to design motors for our vessel, we investigated current means of propulsion that we could integrate into our design. We limited our search to electric propeller driving propulsion systems because they give more power and control than sail or wave energy systems and are significantly less complex to implement.

1) **Outboard and Trolling Motors**
   In the initial stages of research, we investigated electric outboard motor systems for light vessels like kayaks and small boats. Many of the products marketed as “electric outboard motors” are designed for vehicles weighting over 1 ton, which would likely provide more power than necessary while also being prohibitively heavy. Searching instead for trolling motors, we found a variety of options, including the Minn Kota trolling motors used by LLNL on their existing rafts [15]. Trolling motors would generally provide a large amount of power for the raft but are larger and heavier than

other options investigated. The small and light kayak trolling motors like the Torqeedo shown in Figure 9 are promising for their high power to weight ratio but come at a high cost. [16]

Figure 9. Minn Kota (left) [15] and Torqeedo (right) [16] trolling motors.

2) Thrusters

An alternative method of propulsion is the use of thrusters. Thrusters are placed on the bow or stern of a boat. While the main motor on the stern of the boat is responsible for forward motion, bow and stern thrusters are responsible for lateral movement. Traditionally, thrusters are smaller and produce less power than the main propellor, so are more for maneuverability rather than for travel. With two thrusters, a boat can be maneuvered in various ways. By throttling both thrusters in the same direction, translational motion results. By throttling one thruster or the other, stationary turning results. Bow and stern thrusters are helpful for maintaining waypoint position as well as aiding in difficult maneuvers like docking [17]. A commonly used thruster is the T200 developed by Blue Robotics. This thruster has become popular in underwater operated vehicles and Figure 10 depicts their T200 model of thruster. [18]

Figure 10. Blue Robotics T200 brushless thruster. [18]

3) Brushless RC Motors

Even smaller in size and propulsion than thrusters are RC brushless motors. The advantages that come with these motors are the low-cost point and various redundancies, achieving the desired speed and maneuverability. However, these motors need a mount built into the hull, so a special design is necessary to accommodate attachment to a frame. Another aspect that could present challenges is the input wiring. The wires are short to minimize excess wire in an RC boat which, in turn could become a challenge for any larger craft with longer wiring systems. Figure 11 displays some of these challenges on the AquaCraft marine motor. [19]

Figure 11. AquaCraft 28-35-2200 kV brushless in-runner marine motor. [19]

3.0 Objectives

This section will establish the boundaries of the problem that we are addressing for this project. To properly define the targets and scope of the problem, this section starts with a problem statement and boundary diagram. We formalize the customer needs and wants and use them in a quality function deployment process to determine specific engineering specifications.

3.1 Problem Statement

In our customer research, we endeavored to find the root cause of the problem facing LLNL. The interviews with Mr. Nyholm and his colleague Sam Fuller lead us to the following problem statement:

> "Lawrence Livermore National Laboratories needs a better craft to deploy on their missions because their current rafts are large and bulky, making transportation, deployment, storage, and improvement difficult."

This problem statement encompasses what we feel is the root issue at hand: the size and weight of the current rafts inhibits the efficient deployment and travel to research locations. Each raft requires extensive preparation for the month-long journey from one mission location to the next. Furthermore, each mission does not necessarily require the large-scale raft so a smaller alternative could be beneficial [20]. This problem statement will guide the boundary sketch for the problem and the relative importance of customer wants and needs.

3.2 Boundary Sketch

To better communicate the extent of the problem we are going to address, we created a boundary diagram. This sketch, depicted in Figure 12, indicates the parts of the current process on which we will focus design efforts for the LLNL research raft.

In Figure 12, the raft interacts with the larger ship as a part of the mission. The diagram includes a dotted line around the raft, indicating that we will design to address this portion of the entire process. There is a second dotted line inside of the equipment storage container. This second line indicates that we will not be addressing the current equipment and the current control board in our design. We will consider the presence of these components in our design – they are a necessary part of the raft operation – and we will design interfaces with them as needed, but we will not seek to change their design or implementation.

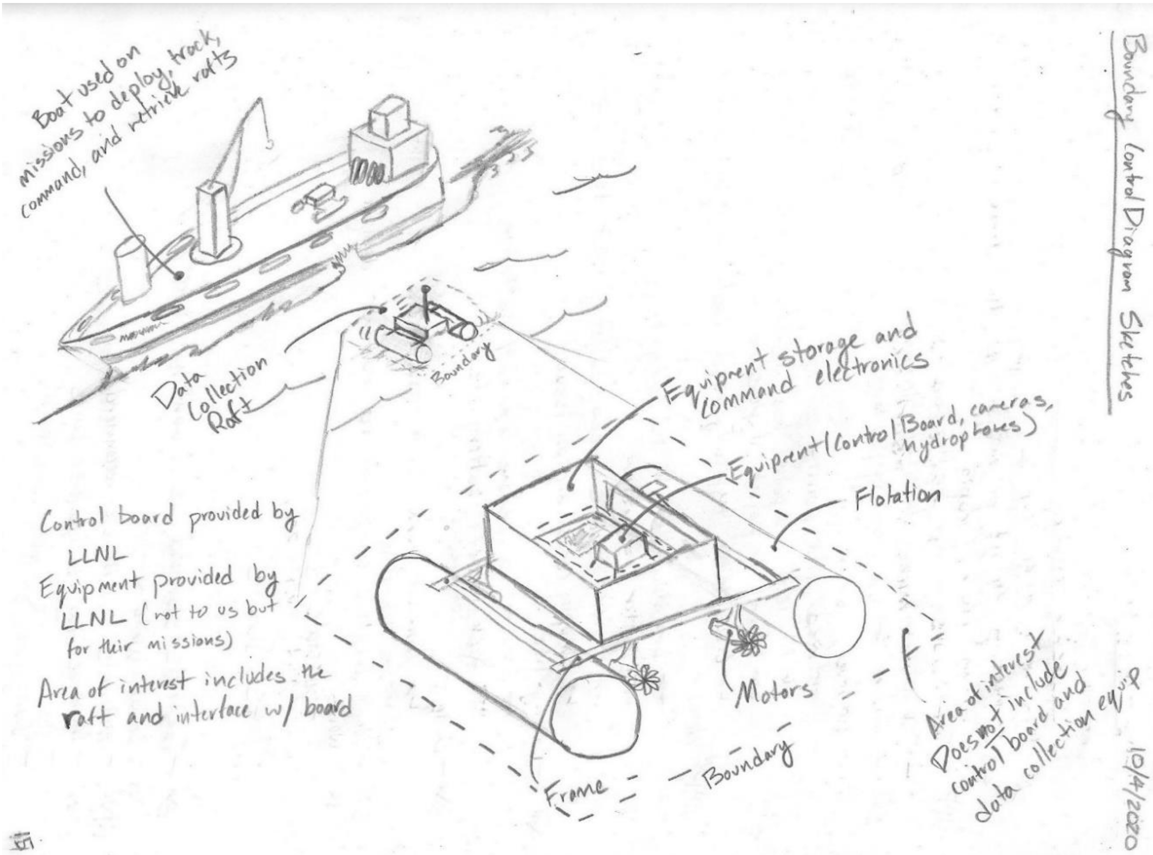


Figure 12. Boundary Diagram for current LLNL Research raft.

3.3 Customer Wants and Needs

From our conversations with Mr. Nyholm and Mr. Fuller, there are three overarching design objectives that we should meet:

1. The raft must be easily shippable.
2. The raft must take up less deck space than their current raft.
3. The raft must decrease reliance on heavy equipment when moving around on deck or in storage.

To meet these objectives, Mr. Nyholm and Mr. Fuller described specific needs and wants for the project. These needs and wants characterize geometry, motion, payload, manufacturing, and cost [19]. Table 2 lays out a complete list of these wants and needs.

Table 2. Customer Needs and Wants with Targets.

	Requirement (Needs)	Goal (Wants)
Weight (w/out battery)	200 lbs.	100 lbs.
Shipping Dimensions	6'x6'x6'	4'x4'x3'
Deck Space / Footprint	4’x7’	-
Stackable	-	2-3 high
Payload	10 lbs.	50 lbs.
Sea State	3-5ft waves, 25 knots wind	> 3-5 ft waves
Motors	2	4
Battery Life	2 days	3 days
Lifting	2 points	1 point
Cost	$15,000	$10,000
Electronics Box	Waterproof	Easy to access
Materials	Resistant to Corrosion, UV, Salt	-
Unit system	-	IPS / English
Fasteners	-	Standard sizes

The “needs” are target values that must be met and are essential to the project, whereas the “wants” target value do not necessarily have to be met but would be beneficial for Mr. Nyholm. The House of Quality section presents a more extensive evaluation of these wants and needs.

Previously, our sponsors indicated a ‘drone landing pad’ as a strong want for this project. While we originally wanted to accommodate this landing pad, we soon realized the complications that it would impose on the design. The landing pad would take up a large amount of space on the raft, and the addition of other necessary components, including the light pole, would make takeoff and landing from the pad difficult. After discussing these complications with our sponsor, they agreed with our decision to refrain from implementing it in our design.

3.4 Quality Function Deployment: House of Quality

The quality function deployment (QFD) method helps us fully understand the objectives to meet when solving this problem, and how to gauge how well we have solved the problem. For our team, this means ensuring that we understood what qualities Mr. Nyholm required for the project and their importance to him. To help understand the problem, we used a House of Quality. The methodology includes following seven basic steps and filling out a table to ultimately capture the “voice of the customer” using engineering specifications. The process starts with defining who the costumers are and what their needs and wants are. Because Mr. Nyholm operates in an engineering environment, he directly provided us with engineering specifications. During this exercise, we needed to determine which aspects of the design were most important to him, prioritizing his list of needs and wants. This proved to be more challenging than anticipated; we asked clarifying questions about the priorities of needs and wants in subsequent interviews with Mr. Nyholm and Mr. Fuller, and these clarifications led us to the decisions in the current House of Quality. [20]

The next step includes weighing these requirements against each customer and identifying which requirements are more relevant to them. Following this, we compared the similar products in 2.2 Existing Product Research to our design requirements to help give us an idea for product improvement. The next step looked at identifying engineering specifications for the project; these specifications are measurable and verifiable aspects for the new design. We took some of these specifications directly from the information given to us, and some were new specifications that the QFD process determined we needed.

From there, we ranked the relationship between the customers' needs and wants to these specifications by determining if the relationship was strong, medium, weak, or nonexistent. Finally, we set up the engineering targets – this meant inputting values and units for both the specifications we chose and for those Mr. Nyholm and Mr. Fuller gave. The full House of Quality is in Appendix A: Quality Function Deployment: House of Quality. From the House of Quality, we produced an engineering specification table.

From the QFD, we were able to measure the importance of each need and want. We listed the customer requirement for "lightweight" and "easily shippable" as the most important factors of this redesign, as expected. Both requirements have the highest relative weight and several relationships to the engineering specifications. We feel that this QFD accurately captures the importance of these two requirements and agrees with Mr. Nyholm's and Mr. Fuller's expectations for this design. [20]

3.5 Engineering Specifications

As the final part of the QFD: House of Quality, we created an engineering specification table. Table 3 shows the resulting engineering specifications and their respective elements.

Table 3. Engineering Specifications.

Spec. #	Specification Description	Target (unit)	Tolerance	Risk	Compliance
1	Weight without battery	200 lbs.	Max	H	I, A
2	Average Footprint on Deck	4'x7'	Max	M	I
3	Cost to Manuf. Final Design	$15,000	Max	M	I
4	Shipping Dimensions	6'x6'x6'	Max	M	I
5	Speed	5 ft/s	Min	M	T
6	Payload	10 lb.	Min	L	A, T
7	Field Assembly Time	5 min.	Max	H	T
8	Battery Life	2 days	Min	L	A
9	Point of Contact	2 Points	Max	L	I
10	Number of Motors	2 Motors	Min	L	I
11	Waterproof	IP66 adherence	Min	M	I, T
12	Stability	Remain upright in 3ft waves	Min	H	T
13	% Purchased Parts	80% OTS Components	± 10%	L	I

The engineering specifications table is the outcome of the QFD process and captures all the needs and wants of the customers as measurable engineering specifications. The table includes assessments of the tolerance of a target – it identifies the target unit as a minimum, maximum, or a bilateral tolerance. The risk column of the table addresses the anticipated difficulty in meeting these target specifications. H, M and L represent high, medium, and low difficultly, respectively. Finally, the compliance column of the table describes the general method we plan to use to test whether we have met these specifications. The four options are: analysis (A), testing (T), inspection (I), and similarity to other products (S).

This list expands on the testing method for each of the specifications in Table 3.

1. Weight will be measured with a scale and with CAD design model properties.
2. Footprint on deck will be measured from final size of the design.
3. Component costs will be tracked over production, to meet the budget.
4. Shipping dimension will be verified by inspecting and measuring the size of design, when prepared for shipping.
5. Speed will be measured by testing the speed of the prototype in water, if possible.
6. The payload capabilities will be tested with FEA models and with physical loading, if possible.
7. Field assembly time will be measured by collecting time data from assembly tests.
8. Battery life will be analyzed based on component power draw during operation.
9. The number of lift points of contact will be verified with a simple inspection.
10. The number of motors will be verified by counting them.
11. Waterproofing will be tested to IP code 66, as best as possible.
12. Stability will be tested by testing the design in wave conditions, if possible. If not, we will test parts of the design, as required.
13. Standard part ratio will be calculated from the bill of materials, counting off-the-shelf purchase parts over unique parts.

While there are desired methods for verifying the target specifications, some of these compliances rely on a full-scale model prototype. Considering effects of lead time and COVID-19 on the manufacturing of the project, we will modify these compliance descriptions based on feasibility of completing the full-scale model.

After conversations with Mr. Nyholm and Mr. Fuller, we have revised our engineering specifications. They indicated that travel range and speed may be redundant specifications, as accomplishing one will accomplish the other. To rectify this, we have removed “Travel Range” from our specifications. Additionally, Mr. Fuller felt that the 5-mph speed was too high. The current rafts reach a top speed of about 5 ft/s; together, we agreed that this would be a better minimum speed target for our raft redesign. The House of Quality in Appendix A: Quality Function Deployment: House of Quality has been updated to reflect these changes. This will have an impact on the concept design, as it shifts the relative weights of the engineering specification used in a weighted decision matrix.

Another edit we made to our engineering specifications was to change “Footprint on Deck” to “Average Footprint on Deck”. We made this change to better represent the needs of LLNL. Using average footprint on deck lets us evaluate our designs based on their overall ability to fit more rafts on deck rather than on just their largest dimensions. The primary example of this would be a raft with dimensions larger than 4’x7’ but which was stackable.

After we made some preliminary material selection decisions, we found that the waterproof container that we want to use meets IP66 standards, indicating that it prevents all dust and powerful water jets from entering. If we were to leave it unmodified, this assurance alone would cover specification 11. However, since we will need electrical connections to pass through the box, this rating may not still hold. To verify that our design meets this specification, we plan to test to IPX6 standards, per standards IEC 60529. These criteria are specific but meeting the standard will ensure that the electronics do not malfunction due to water damage.

4.0 Initial Concept Design

This chapter outlines the initial concept design. The first section describes the process of controlled convergence that the team undertook, leading to a chosen design direction. The next section describes this chosen direction and includes images of a concept prototype and of an initial CAD model. The final section provides some preliminary analysis of the idea, and outlines areas of further investigation and concern.

4.1 Proposal to Initial Concept

With a clear idea of these engineering specifications, we began the ideation process with the end goal of finding a final design direction. This ideation process includes several steps of ideation and refinement, culminating in several system level concepts from which we could choose.

4.1.1 Function Tree and Functional Decomposition

The initial step in the ideation process included breaking down and identifying the basic functions of our design, through functional decomposition. Doing so allows us to evaluate each function individually to better understand how these basic functions fit in the overall design. We illustrated the results of this process in a function tree, as shown in Figure 13. The tree begins with the most general function that the design must achieve. For this craft, we determined that the overarching objective is to facilitate research. From here, we identified subfunctions; these are secondary functions that the craft needs to achieve, represented on the second tier of the tree. From these subfunctions, we identified various basic functions. These basic functions are the lowest tiers of the tree, indicating that we could not break them down any further. Breaking down the design into these basic functions allows us to ideate on each function and fully explore solutions independent of other functions.

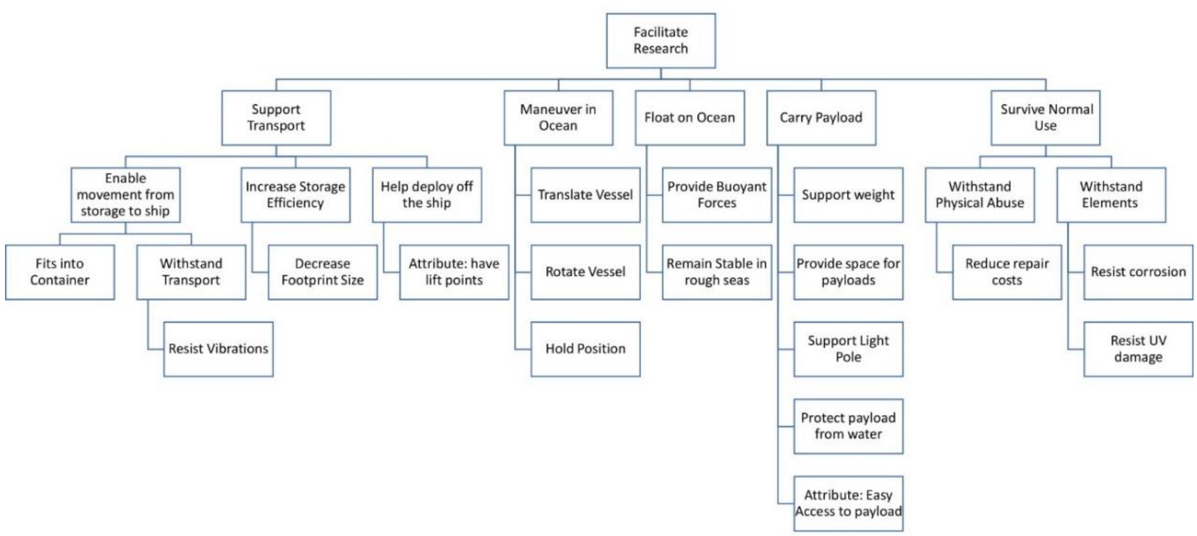


Figure 13. Function Tree Depicting Functional Decomposition.

4.1.2 Function Ideation

Once we completed the functional decomposition process, we began brainstorming ideas for each basic function. Our goal for this stage of ideation was to maximize the quantity of ideas generated. We approached these brainstorming sessions with an exploratory attitude, generating as many diverse ideas as possible. We used Google Jamboard to document ideas from six to ten-minute brainstorming sessions. With a timer set, we performed brain dumps of our ideas, collecting them on virtual sticky notes. This method helped us produce large quantities of ideas for each function, which we then refined and evaluated. Documentation of these brainstorming session is in Appendix B: Brainstorming Session Results.

Another technique we used was to sketch an idea for a basic function and pass the sketch along to other team members to sketch additions and improvements. This helped us visualize possible ideas to solve the basic functions and we show these results in Appendix C: Sketching Ideation Results. Once we were satisfied with the quantity of ideas generated for each function using either method, we began idea refinement.

This initial stage of idea refinement, known as controlled convergence, includes briefly evaluating each idea that we generated. The criterion for refinement was purely whether each idea was feasible or not. We weighed heavily on engineering judgement to refine these ideas, and as a result, ended up with a shorter, yet higher quality, list of ideas.

4.1.3 Concept Modeling

Satisfied with our refined list of ideas, we explored some of the leading ideas further. To do this, we created concept models of these top ideas for some functions. Concept modeling helped conceptualize our ideas and allowed us to perform preliminary tests and evaluations while simultaneously helping generate new ideas. We created several concept models for our basic functions to help gain a physical understanding of how these ideas may work. The goal of these concept models was to test the assumptions that we had made during idea generation and see if ideas were viable. We focused on creating simple models, hoping to produce large quantities. We each created five to eight concept models and then presented our models to the rest of the team to discuss what we learned while building them. Figure 14 through Figure 16 show examples of concept models, along with brief explanations of what we learned from them.

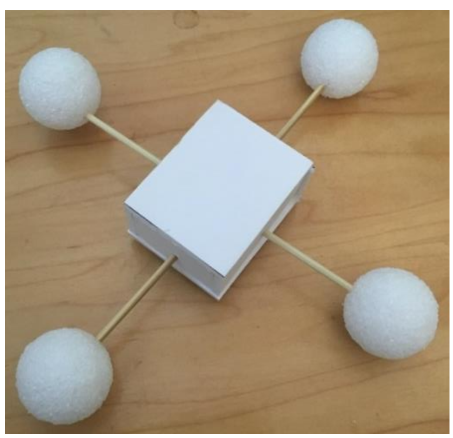


Figure 14. Concept Model for ‘Stability’ Function: Water Strider.

While discussing options for providing stability for the craft, we generated the water strider idea. This idea surrounded the payload with multiple round buoys, to stabilize the craft in all directions. To test this concept, we placed the model in Figure 14 in water, to observe the effects of waves on its flotation. One observation from this model was that the payload should be above the center of the flotation devices, to keep the payload away from the water.

Figure 15. Concept Model for 'Provide Space for the Payload' Function: Shelving Frame.

While exploring options for ‘Providing Space for the Payload’, we considered shelving component as seen in Figure 15. This concept gave us a feel for how the battery and payload would fit in more compact space. We learned that implementing this system would require that the payload and battery be able to slide in and out of the shelves, which would be tedious considering the size and weight of the payload and battery. However, this model did inspire potential ways to stack the payload that would not require additional supports.

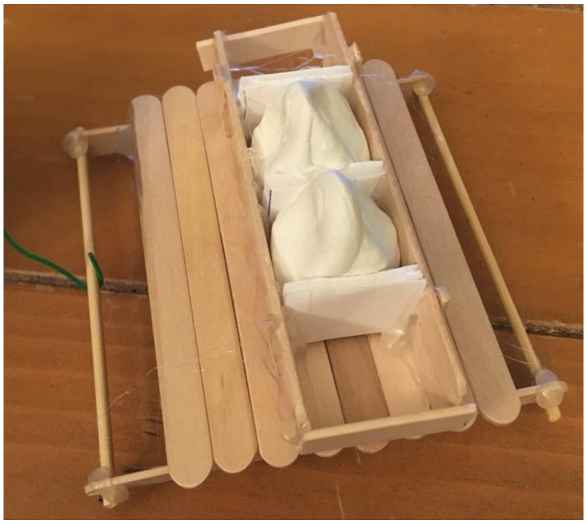


Figure 16. Concept Model for 'Have Lift Points' Function: Side Rail Lift.

Figure 16 explored a concept for the function of ‘Have Lift Points’. We wanted to explore a way to life the raft using secondary frame members as a location for a lift point. This would eliminate the need for a specialized location on the frame to act as a target for the crane hook. However, with simple testing, we observed that using this side rail lift point caused unstable and unpredictable movement of the craft when lifting it.

While these figures highlight takeaways from some of our concept models, we created several others, all tabulated in Appendix D: Concept Models**.** While none of these are a fully functional prototype, each model provided insight into potential design challenges. Creating these concept models helped move our team towards a more realistic path for our design direction. From here, our team continued the refinement process by assessing our top function ideas in a series of Pugh matrices.

4.1.4 Pugh Matrices

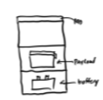
The next step in the controlled convergence process was to combine, refine, and evaluate the ideas developed during both ideation and concept modeling. To accomplish this task, we used multiple Pugh matrices – one for each of the major basic functions from the function decomposition process.

To create these matrices, each team member chose two functions to investigate. We already combined some basic functions during the ideation sessions; translate vessel and rotate vessel fell naturally together during this process. We refrained from including some functions in this process because they were difficult to convey with a simple description or pictorial. We also omitted some because we either felt it was not necessary to iterate further on the ideas or reasoned their implementation would not affect the design until later in the process.

The result of this process was a comparison of ideas to a standard for each of the customer wants and needs that we identified in the QFD process. For each function, a member sketched five to ten of the top ideas from the refined ideation session. We arranged these ideas as the headers of columns in a table, like the one shown for the Provide Space for Payload function in Table 4. The rows of the table contained customer wants and needs that were applicable to the function in question, and it was along these criteria that we judged ideas.

To start, we designated one idea as the datum, against which we would compare the rest of the ideas. Where possible, we chose to use the current solution on the LLNL research rafts as the datum, comparing new ideas to it. For each need and want, ideas were determined to perform the same as (S), perform better than (+), or perform worse than (-) the datum. We totaled the numbers of S, +, and – for each idea; while tempting to sum linearly, we refrained from doing so as the comparisons did not give a magnitude of the performance of the idea, only the direction of change. Fortunately, this system still allows for us to make comparisons between the ideas. Ideas with more + are generally more favorable, and ideas with fewer – are generally more favorable.

Table 4. Pugh Matrix for Provide Space for Payload.

Ideas and Sketches	Current Frame with Metal Box	Below Deck in Hull	Exoskeleton frame w/t boxes	Mounted to deck surface	Payload structure is boat
Customer Wants and Needs					
Lightweight	S	+	S	+	+
Easily Shippable	S	+	+	+	-
Drone Pad Compatibility	S	+	+	-	S
Resistant to Corrosion	S	+	S	-	S
Standard Fabrication	S	-	+	+	-
Stackable	S	S	+	-	-
Payload Weight	S	S	S	S	S
Sum +	**0**	**4**	**4**	**3**	**1**
Sum -	**0**	**1**	**0**	**3**	**3**
Sum S	**7**	**2**	**3**	**1**	**3**

From here, we considered the best parts of the worst ideas for implementation on another idea, and the worst parts of the best ideas for general improvement. This allowed us to take the good aspects of an otherwise poor idea and combine these together, and to shore up the weaknesses on otherwise strong concepts. This lead each of us to a new phase of ideation, combining the old ideas with the new findings.

After considering these faults and strengths, we sketched eight improved concepts. These concepts included ideas from the Pugh matrix itself and from the ideation afterward. This new set of ideas became the foundation of the morphological matrix, the next step in the process of controlled convergence. Appendix E: Pugh Matrices shows the results of the Pugh matrix process for each of the eight chosen functions.

4.1.5 Morphological Matrix

The results of the Pugh matrix convergence were the top eight ideas that solved each function. Up to this point in the design process, we had considered the functions individually. The morphological matrix tool brings these separate refinement processes together into a single matrix. This matrix lists the solutions for each idea in a separate row. System level concepts are generated by selecting one solution for each function and combining them together. To create these combinations, we relied heavily on engineering judgment and descriptions of the function solutions to find what we felt were the best combinations. The full morphological matrix is in Appendix F: Morphological Matrix. Shown there are the solutions we indicated each system would use to address specific functions.

The Aluminum Monohull concept in Figure 17 consists of a hollow aluminum hull in which the payload and battery are stored. A motor would mount to the back of the hull to propel the vessel forward, and a laterally facing thruster at the bow and stern would allow the vessel to rotate or move side to side. The small size would be its primary advantage in facilitating transport and reducing deck space.

The Surfing Raft concept in Figure 18 consists of a foam-core surfboard-like flotation device upon which the payload and battery are mounted. A thruster on either side of the board would allow the vessel to move forward and turn. This design would be long and thin, taking up little space on deck.

The Rubber Catamaran concept in Figure 19 is like the existing Laurence Livermore raft: two rubber pontoons connected by a metal frame. Mounted to this frame and sitting between the pontoons would be the payload, battery, and light pole. This design would stack to decrease the footprint on deck.

The Folding Trimaran - Rubber concept shown in Figure 20 and the Folding Trimaran – Fiberglass in Figure 21 were very similar overall, with a few key differences. They both consist of a larger center hull with two pontoons extended out to either side for stability. These side pontoons fold horizontally to reduce the footprint of the raft. The main differences between them are the material of the hulls – the first is rubber and the second is fiberglass – and the location of the payload. The rubber trimaran would have both the battery and payload mounted on top while the fiberglass trimaran would have the battery within the center hull, with the payload on top.

The Water Strider concept in Figure 22 took inspiration from the insect of the same name. The craft would consist of six arms with flotation at the end connected to a central frame holding the battery and payload. This design could stack to reduce deck space and the arms could be removed for transport. A single central lift point would be used to deploy the craft.

The Telescoping Trimaran in Figure 23 was like the other trimaran concepts but used telescoping poles to retract the pontoons and reduce the craft's footprint size. Like the Folding Trimaran – Rubber, the payload and battery would be mounted on top of the center hull.

The Truss Catamaran in Figure 24 consists of a truss structure frame connecting two pontoons made of joined and capped PVC pipes. The payload and battery would be supported by this truss frame between the pontoons. This design would also stack to reduce its footprint on deck.

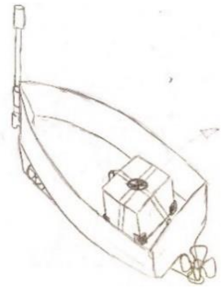


Figure 17. System Concept: Aluminum Monohull.

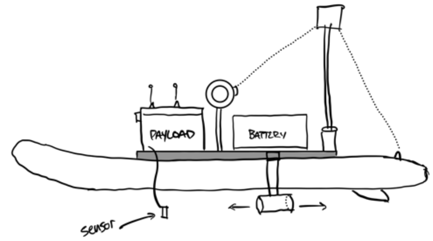


Figure 18. System Concept: Surfing Raft.

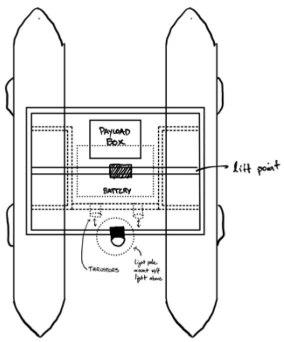


Figure 19. System Concept: Rubber Catamaran.

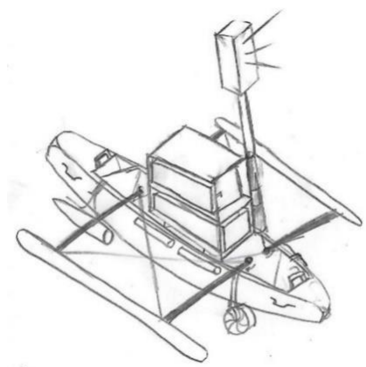


Figure 20. System Concept: Folding Trimaran – Rubber.

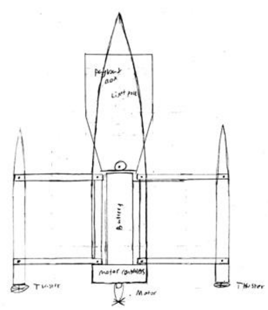


Figure 21. System Concept: Folding Trimaran – Fiberglass.

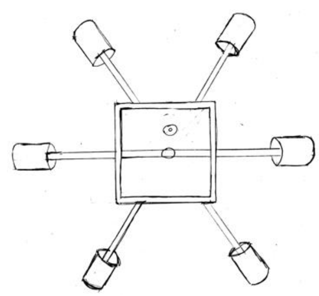


Figure 22. System Concept: Water Strider.

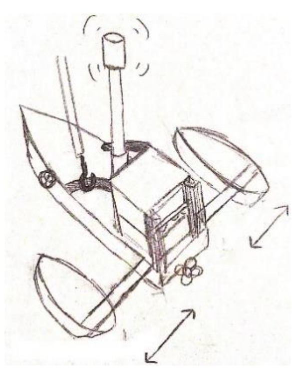


Figure 23. System Concept: Telescoping Trimaran.

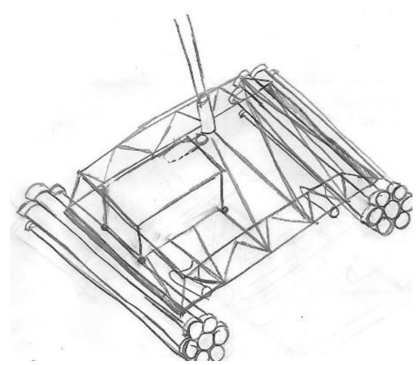


Figure 24. System Concept: Truss Catamaran.

Each of these system solutions stemmed from one set of choices in the morphological matrix. Some similarities between ideas is normal, as some function solutions fit well with other function solutions, but the differences between the ideas was also helpful to us. These differences allowed us to better understand how functions interacted and influenced one another, which is a large part of the weighted decision matrix process. Once we created and shared these system level sketches, we started on that evaluation process.

4.1.6 Weighted Decision Matrix

Our system level sketches communicate our design ideas, but they do not indicate which idea would be best suited to meet the design challenge. To decide on a final design direction, we used a weighted decision matrix. During the Pugh matrix process, we rated each idea on the extent to which it addressed customer wants and needs, as we had not refined the ideas enough to warrant judgement against the engineering specification. For this process, the ideas are robust enough to support ratings based on the more specific engineering specifications. Appendix G: Weighted Decision Matrix displays the complete table of ideas, criteria, weights, scores, and totals.

For our weighted decision matrix, the engineering specifications and weights came directly from the QFD: House of Quality process. We completed the scoring process for each system solution in two separate steps. We initially rated each idea for each specification, scoring down each column. This allowed us to get a holistic view of each idea and really understand the strengths and weaknesses of each. Upon completing this process, we felt that the scores needed standardizing, so we reevaluated the scores for each engineering specification. This second pass compared ideas to one another, and we were able to gain a better understanding of the features that improved a design's performance on each specification. Appendix G: Weighted Decision Matrix also includes notes from our discussion.

4.2 Selected Initial Concept

We chose the Catamaran in Figure 19 for our intended design direction. We selected our initial concept by evaluating all the information and conclusions from the ideation process, and especially the results in the weighted decision matrix. This tool played a crucial role in providing clarity on the general design direction, and our selected concept section focuses on defining major features and relations in the overall raft design. Key elements for the selected design are in Table 5 and Figure 25 shows the selected concept, with a visual reference to key elements on the raft.

Table 5. Solutions to Key Functions of Design Direction.

Key Function	Chosen Solution
Footprint Design	Catamaran
Flotation Type	Inflatable Rubber Pontoons
Decrease Footprint	Stackable Design
Support Light Pole	Mounted Support
Frame	Exoskeleton with payload mounted to structure

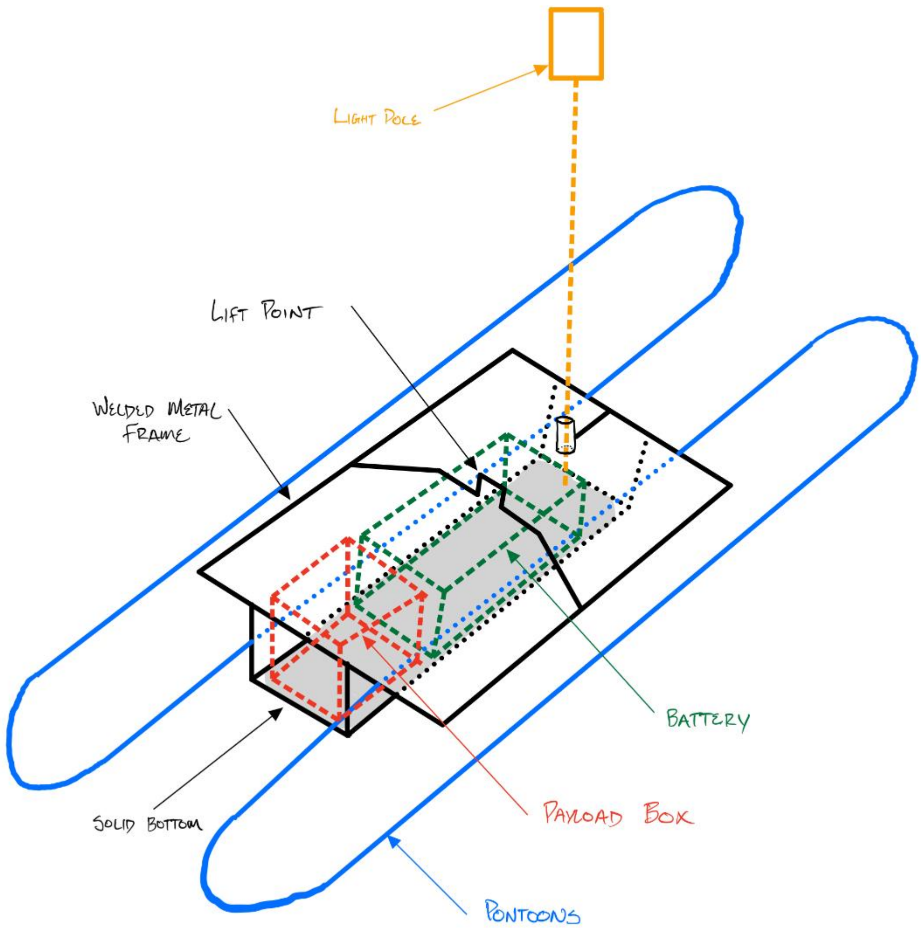


Figure 25. Detailed Sketch of Design Direction.

We included key elements in the concept sketch, with the goal of meeting the customer needs in mind. The rubber pontoons will provide buoyancy for the raft and their inflatable nature can reduce the overall size for shipping and transport while deflated. The sketch highlights the payload and battery placement between the two pontoons, lowering the center of mass to help counteract the instability introduced from the light pole. The light pole secures to the craft with a mount attached to the frame. The pole will be removeable to minimize overall size during transport and storage. We intend for the crane to life the raft from the launch boat to the water via a single lift point located above the raft center of mass. The single connection point will minimize deployment time and the location over the center of mass will ensure stable travel through the air. The frame structure will consist of aluminum and connected to maximize durability in the oceanic environment. The specific motor configuration has not been determined in this stage, but the selected design allows for variability in location and quantity. Motor placement and quantity will be dependent on requirements provided by LLNL and we will define these in the critical design phase. In the same vein, the manufacturing and assembly processes will be determined in the critical design phase, with the goal of introducing design for manufacture and design for assembly techniques.

4.3 Preliminary Design Analysis

Having selected the initial design, we started some preliminary analysis to justify the design direction. This justification includes concept CAD models, a concept prototype, rough engineering calculations, and the potential risks and challenges that we expect to encounter and address with this design.

4.3.1 Concept Prototype

We constructed a full-size concept prototype frame to model the relative dimensions and layout of the concept model selection. The goal of this prototype was to gain insight about the expected overall design dimensions, payload area, and material requirements. We constructed the model in Figure 26 with 40 feet of ¾ inch PVC pipe and various pipe connections. The frame length and width are 52 and 36 inches respectively and the light pole is seven feet tall. One of the critical dimensions that the prototype focused on modeling is the central lift hook height. The central lift hook needs to provide clearance for the battery, housed underneath it. The prototype utilized the dimensions from the current battery that LLNL uses on their research craft, which resulted in a lift point height of 17 inches. The orange buckets that are supporting the frame do not represent the true dimensions of the inflatable pontoons but are there as a visual aid.

Figure 26. Isometric view of the concept prototype.

We made a few important observations once the prototype was complete. Primarily, we noted that the payload area is very compact. This factor will need consideration throughout the detailed design process, as space management will be critical. Another important observation made was that the central lift point could potentially interfere with the stacking of the rafts. The central lift point will need modification such that stacking is possible; we will need to add clearance to the underside of the rafts or consider design configurations. Future progress in the detailed design will guide the choice of these options.

All the observations and information learned from the concept prototype will guide the detailed design of the final concept. We can easily modify the prototype; we will use this to help us test and visualize future progress. Appendix H: Concept Prototype includes additional concept prototype documentation.

4.3.2 Concept CAD

To create an initial model of the concept with approximate dimensions, seen in Figure 27, we used SolidWorks 3D modeling software. Parts like the battery and light pole with known dimensions and masses are relatively accurate, but the dimensions of frame member, pontoons, and the payload box are preliminary. To get an understanding of how component location affected center of gravity (CG) position, we estimated masses for all components. SolidWorks calculates an assembly CG, that updates as components move, which allowed us to rearrange components to find a layout with a low and centered CG for improved stability.

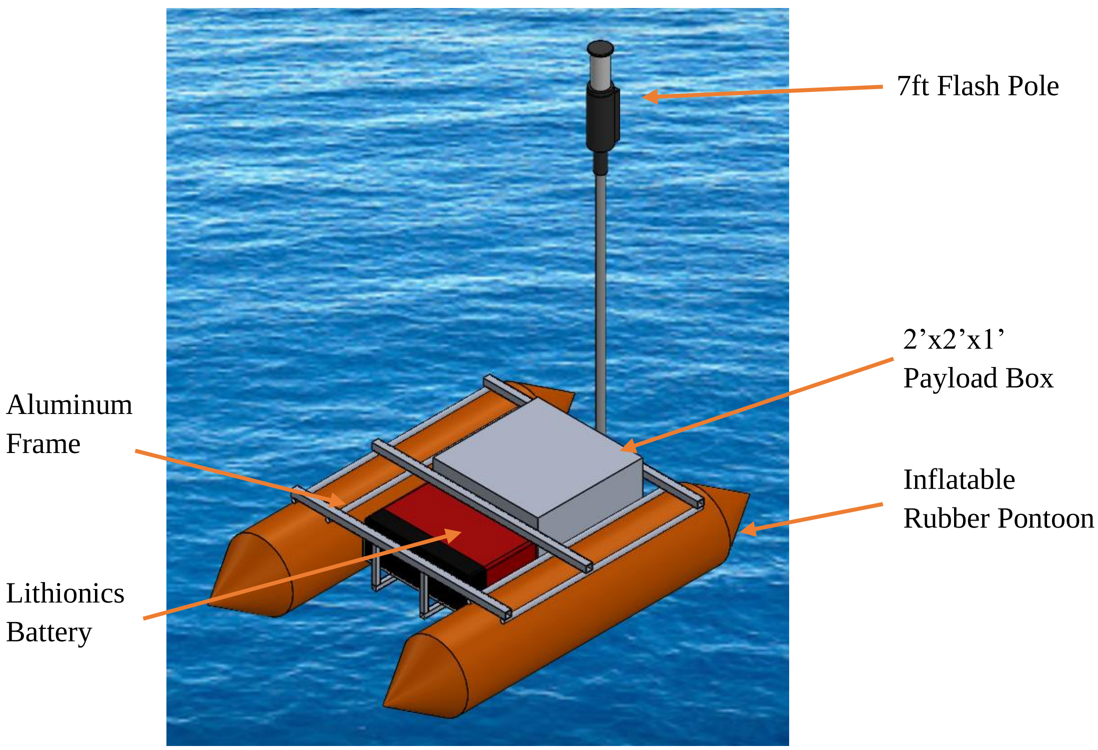


Figure 27. Labeled initial CAD model of the selected concept.

Figure 28 shows a side view of the model with the CG height and position. As components become more defined, we will update them in this CAD model to get a more accurate CG location. Future CAD work includes adding motors and motor attachments, as well as refining the frame design and pontoon attachment. We also need to confirm with the battery manufacturer that we can install the batteries on their side, as this affects the layout significantly. Figure 29 shows a side by side of our concept with a model of LLNL’s current raft provided to us. Putting the two models side by side helped us understand the scale of our concept and how it would significantly save deck space. The model also helped visualize was how the rafts would stack, as in Figure 30. Using this view, we were able to confirm the feasibility of stacking. We will also use it during detailed design to ensure there is clearance between nonstructural raft components when stacking.

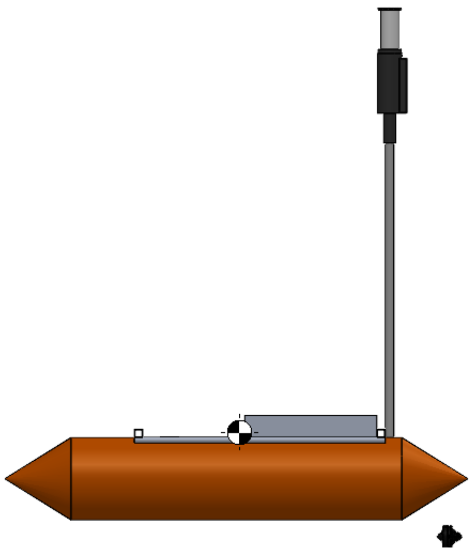


Figure 28. Side view of selected concept model with CG location.

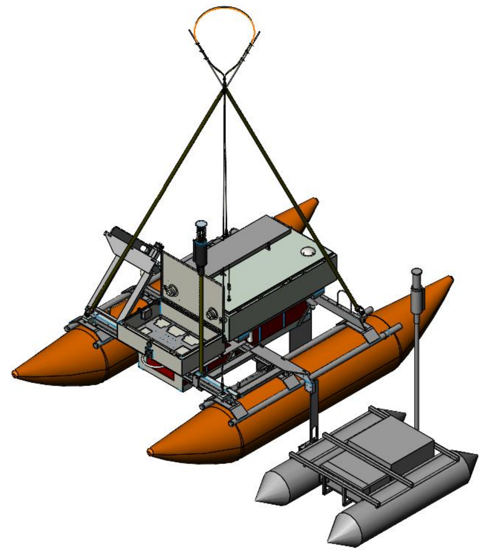


Figure 29. Side by side of current LLNL raft CAD model and our concept CAD.

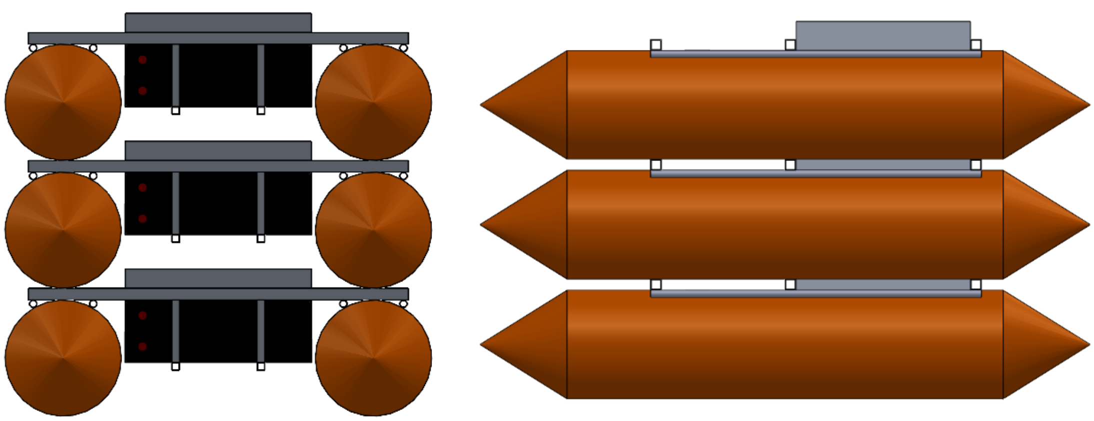


Figure 30. Initial SolidWorks model demonstrating raft stacking.

4.3.3 Preliminary Calculations

We performed a preliminary calculation of the buoyant forces needed to keep the raft afloat. We assumed the raft weight to be 350 pounds, including the battery, corresponding to the upper limit of raft weight defined in our requirements. The total buoyant force on the vessel must equal the force of gravity for the craft to be in static equilibrium. The buoyant force is also equal to the weight of water displaced by the craft. Using the relevant formulas, we calculated the submerged flotation volume required to sustain the raft is 5.54 ft^3. Using two pontoons, each one would need 2.77 ft^3 of submerged volume. We will use these calculations to size pontoons moving forward to ensure that the frame sits above the waterline. Full calculations are in Appendix I: Preliminary Buoyancy Calculations.

Initial evaluation of stability began once we selected the intended direction for our design. The driving factors of stability for the craft in varying seas are the half beam dimension, the moment of inertia around the axis of rotation, and the frequency of the waves. The half beam dimension is half of the deck width, so regarding our design, half of the distance between the center of each pontoon. Evaluating the relation of these three dimensions yield the stability conditions that we can expect from the craft in a set of environmental conditions. This initial preliminary evaluation focused on identifying the key elements that affected the overall stability of the raft. More conclusive calculations of these stability variables and stable conditions will take place after selection of the final design configurations and components. The documentation for the preliminary evaluation is in Appendix J: Preliminary Stability Calculations.

4.3.4 Risks and Challenges

With this preliminary concept design selected, we are starting to discuss possible hazards and risks that accompany this design. We acknowledge that some of the hazards discussed will not be completely resolvable; we will create warning documentation and usage instructions for users to minimize these potential risks. While we should not neglect to include this information, it is safe for our team to assume that the people operating this raft will already have some technical understanding of how to deploy these crafts. This institutional knowledge greatly increases the general awareness of failure points, and so we will not need to be as explicit with their enumeration. This section will outline the design hazards our design will face and some possible action plans towards resolving them.

One hazard that we must take into consideration is the size and weight of this craft. While we assume that trained workers will be operating the retrieval, deployment, and transportation of this craft, we will ensure that we outline a protocol for the safe handling and use of the raft. This is a safe assumption, the deployment of these rafts is a complicated technical process, and any personnel involved will have undergone some training. Regardless, we will create documentation to convey this protocol to those who handle the craft. When further considering the weight of the craft, we also understand that the frame of the craft must be able to withstand its own weight during lifting operations. To mitigate frame failure, we plan to conduct stress analysis on the frame to ensure that chances of failure are few.

Another risk identified is the revolving motor blades: when running, these motor blades have the capability to cause damage to any user or nearby objects. Therefore, we plan on either implementing a guard around the blade or to ensure that we place the blade in an area that will decrease potential contact while it is running. When considering battery voltages, we want to ensure that user is aware of the risks that come with running a large battery; thus, we plan to place sufficient warning labels to inform the user of the potential risks.

The discussions listed above serve as initial approaches towards finding a resolution to our potential hazards. The complete design hazard checklist is in Appendix K: Design Hazard Checklist. As we begin detailed design and look further into finalizing our design, we will input additional hazards and action plans or update current action plans as deemed necessary.

We would also like to acknowledge the design challenges that we foresee for this project. When comparing the desired size of the raft and the target specification for stability, we anticipate that finding an optimal balance between the two specifications will prove to be difficult. While a small footprint is necessary, as we decrease the size, we also decrease the stability of the raft. In addition, we determined that the battery and payload are strong driving factors for the design, affecting several key functions such as the footprint, stability, and stack-ability. The custom size and diameter of the proposed pontoons may also be difficult for a company to manufacture, which would force us to consider different pontoon sizing options. Finally, our current size and location of the lift point may cause stacking issues, but we will further evaluate and address these during the detailed design phase.

5.0 Final Design

This chapter details the final design that we have submitted to LLNL. We have incorporated the feedback from our various design reviews and feel that this final design meets the specifications previously determined in section 3.5 Engineering Specifications. This chapter contains the details for the various subassemblies in the final design, the safety analysis for the system, and the final cost of the assembly.

5.1 Overall Design

This section lays out the detailed design for each subassembly in the system. The main raft assembly is comprised of two major assemblies: the frame assembly and the pontoon assembly. The frame assembly consists of the frame itself, the motor mount subassemblies, the payload and battery subassemblies, and the light pole subassembly. The pontoon subassembly consists of the pontoons and pontoon fixturing. Figure 31 is a render of the raft SolidWorks model with assemblies labeled.

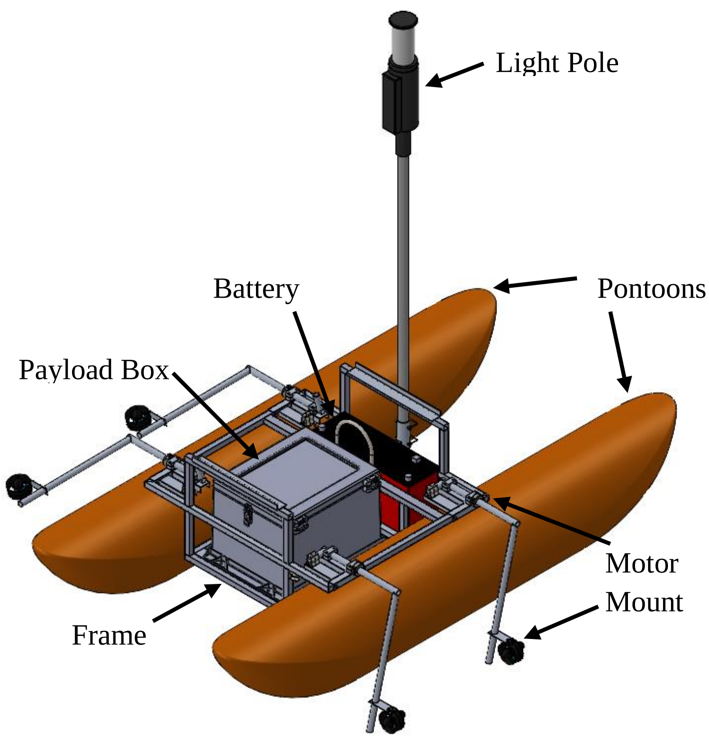


Figure 31. SolidWorks model of the full raft design.

Table 6 presents a breakdown of the initial predicted total raft weight by subassembly, based on component specification sheets and weight estimates from the SolidWorks model. Appendix L: Indented Bill of Materials shows a comprehensive breakdown of all the parts in the final design, by assembly and subassembly. Appendix M: Drawing Package shows the complete drawing package for all the parts in the final design, including modified and purchased components.

Table 6. Frame Weight Breakdown.

Subassembly	Predicted Weight (lbs.)
Pontoons	40
Frame	23
Motor Mounts*	13
Battery	67
Payload Box	30
Light Pole	18
Total	**191**

*Includes motor weight

5.1.1 Frame Subassembly

The raft frame consists of three distinct levels, manufactured primarily from 6061-T6 square aluminum tubing. The lower deck supports the payload box and battery. The main deck contains the central lift point, the light pole holder, and supports the pontoons. The motor attachments connect to the main deck above the pontoons. The upper deck is the support system that enables stacking of the rafts. Vertical supporting bars connect the three levels and when welded together, combine the levels in a rigid frame. The overall frame is 39 inches wide, 34 inches long, and 20 inches tall, which is small enough to meet our shipping specification. Figure 32 and Figure 33 show views of our standalone frame SolidWorks model.

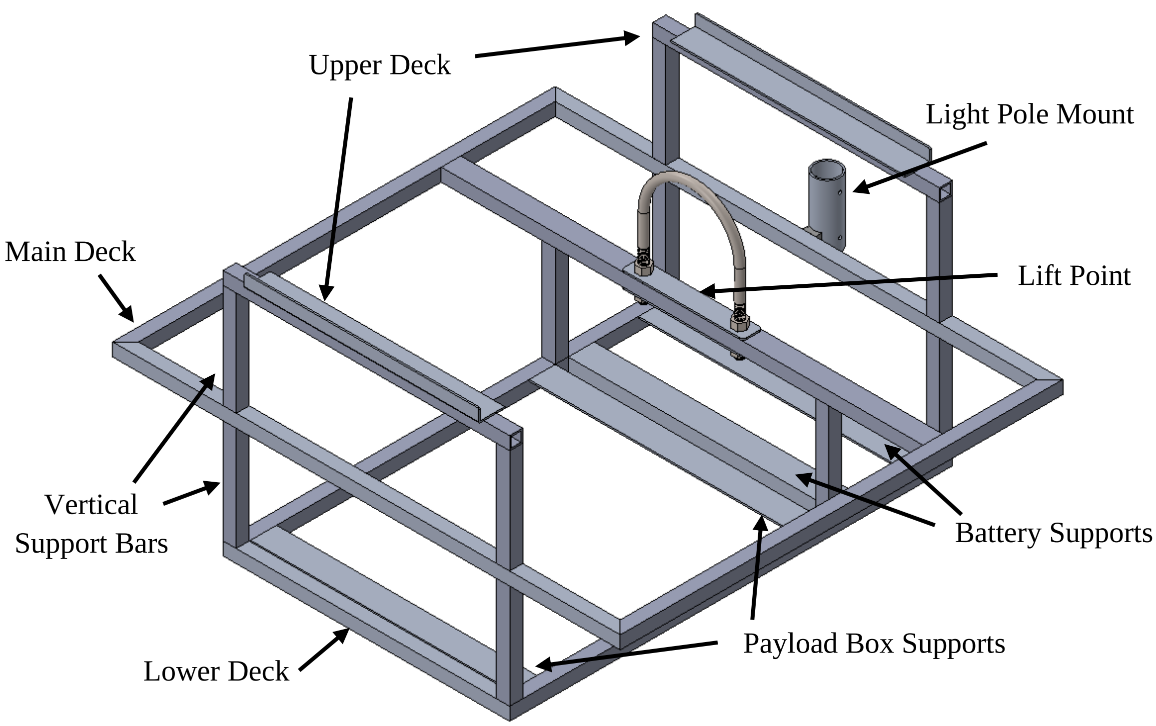


Figure 32. SolidWorks model of the raft frame.

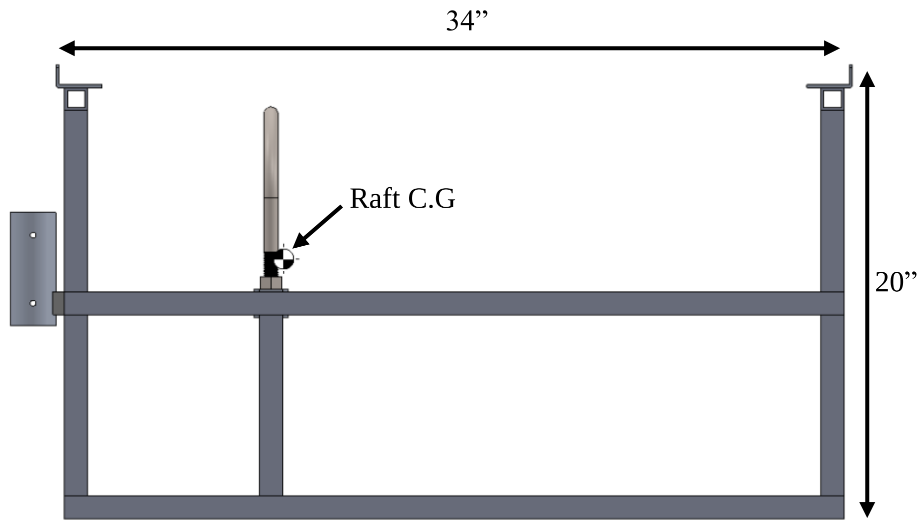


Figure 33. Side view of the raft frame model with full raft CG location for reference.

The lower deck is 22 inches wide and 34 inches long. The primary members are 1-inch square tube stock while the secondary support members are 1-inch by 2-inch angle stock. Both the battery and the payload box have two secondary support members. The members used to support the payload box each have two holes such that four bolts secure the payload box in all axes of motion. The battery support members each have two slots such that two 1-inch NRS straps can secure the battery to the frame.

The main deck contains the lift point support member to which we have mounted a single U-bolt. This U-bolt provides the primary attachment point to lift the raft for transport or deployment. The primary members in the main deck are 1-inch square tube and the central member supporting the lift point is a 1-inch by 1.5-inch tube. The lift point is located above the center of mass to maximize stability when lifting. The U-bolt mounts though holes in the support member, secured by four nuts. U-bolt mounting plates on the top and bottom of the central frame member provide additional support and help alleviate stress concentrations created by the large diameter holes. Figure 34 shows the lift point and the members that help support it.

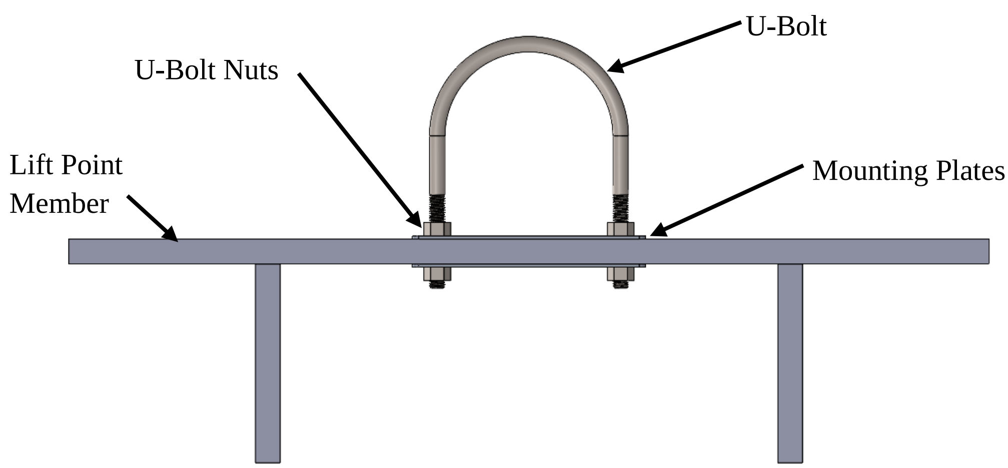


Figure 34. Lift point U-Bolt and lift point member.

For the light pole attachment tube, welds will hold it to the front of the frame and utilize two cotter pins to secure the pole itself. The side members on the main deck have two lateral holes at the front and back where the motor mounts attach easily with a pair of bolts. Additionally, a small drain hole is located on the bottom of the front and back frame members such that any water entering the frame through the motor mount holes will self-evacuate.

The upper deck's role is to support the stacking function of the crafts on the ship deck. The primary members are 1-inch square tube while the secondary support members are 1-inch by 2-inch angle stock. The bars rise vertically 9 inches and have welded angle stock on the top to retain the stacked rafts' bow and stern motion. The pontoons contact the frame on either side of the upper deck while stack, constraining any potential lateral motion of the raft. The angle stock is large enough to provide a half inch of clearance on both ends to make stacking the rafts easier while on a moving ship out in the ocean.

5.1.2 Frame Analysis

To ensure that the raft would survive operation by Lawrence Livermore, we performed calculations by hand and using ABAQUS FEA for three loading cases.

1. Lifting: Represents the load on the frame when the crane on the larger ship lifts the raft for transport or deployment. The weight of the raft itself pulls down on the raft while the lift point reacts those forces.
2. Ground stacking: Represents the load on the frame when it sits directly on the ground and supports stacked rafts above itself. This would require either the deflation of the pontoons on the bottom raft or use of an external structure to support the bottom frame, raising the pontoons above the ground. The rafts would stack this way when stored long term, transported, or when taller stacking on the ships' deck is desired.
3. Pontoon stacking: Represents the load on the frame when the pontoons remain inflated and support a stacked raft on top. This also serves as an extreme case of normal ocean operation, since the load reacted by the pontoons is double that of a single raft.

We considered a fourth case to represent the torsion but not analyzed due to time constraints on the project. This loading case would have looked at stress and deflection of the frame when the forces on the pontoons are not balanced around the center of the frame. Part of the reason we did not implement this loading case in our FEA was because we did not have a good way to quantify the twisting loads on the frame. We suggest performing further analysis to quantify these loads and investigate the frame's response before LLNL fully implements the rafts.

We performed hand calculations to obtain preliminary sizing of frame components with standard tube sizes. We chose aluminum as a frame material for its corrosion resistance and low density, specifically 6061-T6 for its low cost and high weldability compared to other aluminum alloys. We selected a single tube size of 1 inch square to simplify mounting and wall thickness was determined using strength and stiffness criteria. We considered standard wall thicknesses of both $1/8^{th}$ inches and $1/16^{th}$ inches. Hand calculations, found in Appendix N: Frame Hand Calculations, showed that higher stressed members, like those on the main deck, would require $1/8^{th}$ inch wall thickness, while other members could use $1/16^{th}$ inches. After speaking with shop techs and a certified welder, we found that using mixed wall thickness would make the welding process significantly slower and more difficult, as 1/16th inch is easy to blow through. We chose to specify 1/8th inch wall thickness for all frame members since it only increased the frame weight by 2.5 pounds and greatly increased manufacturability, as well as increasing frame stiffness and safety factors.

After preliminary sizing, we used ABAQUS CAE software to model the frame and perform Finite Element Analysis (FEA). We modeled each frame member individually using shell elements and tied these members together to form the assembly. Using this model, we subjected the frame to the three loading cases described earlier to find areas of high stress, especially focusing on weld locations. Details of analysis parameters and loading cases are in Appendix O: FEA Parameters and Loading Cases. In all loading cases, we observed that the locations of highest stress were at welded joints. The elevated stress levels are resultants of frame geometry and stress concentrations found in the connections between frame members. Figures 35-37 show the Von Mises stress results of our FEA, at the locations of the highest stress for each loading case.

For the lifting case shown in Figure 35, the areas of highest stress are around the fillet welds between the rectangular lift point member and the square vertical members that support it. For the ground stacking case in Figure 36, the areas of max stress are at the fillet welds between the horizontal upper-deck member and the vertical support members. For the pontoon stacking case shown in Figure 37, the areas of max stress are at the front corners of the main deck where the length and width members meet at an angle. There is also high stress where the main deck width member meets the two vertical members connecting it to the upper and lower decks in the pontoon stacking load case. Safety factors for these high stress areas are in Table 7.

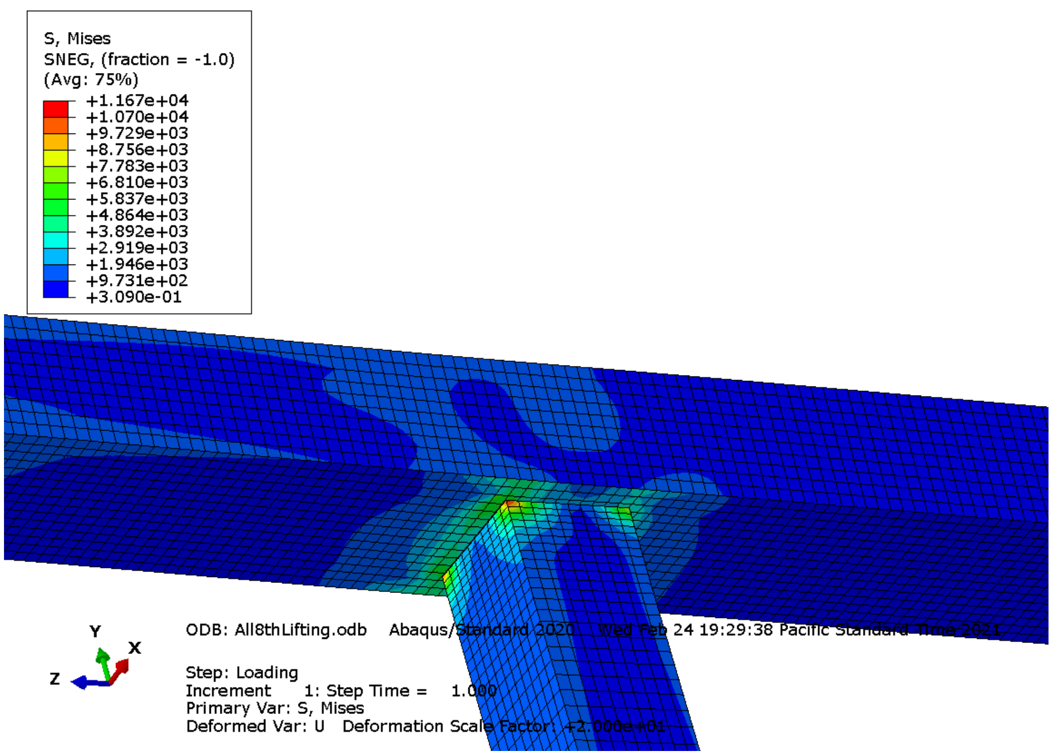


Figure 35. Lifting load case stress results zoomed in on the area of highest stress.

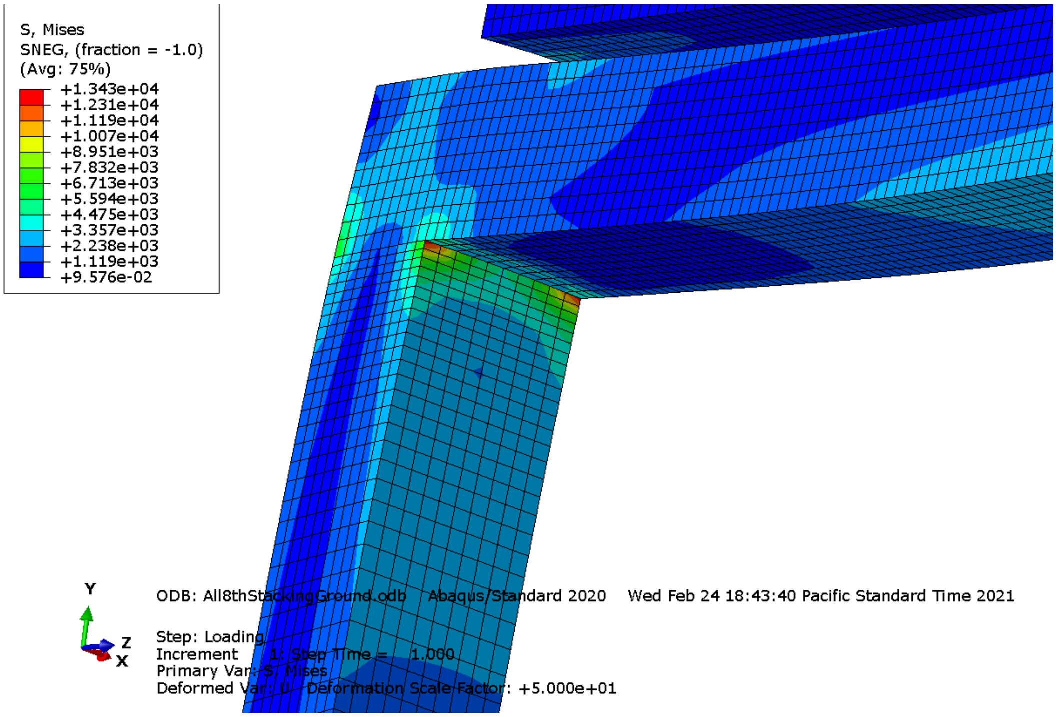


Figure 36. Ground stacking load case stress results zoomed in on the area of highest stress.

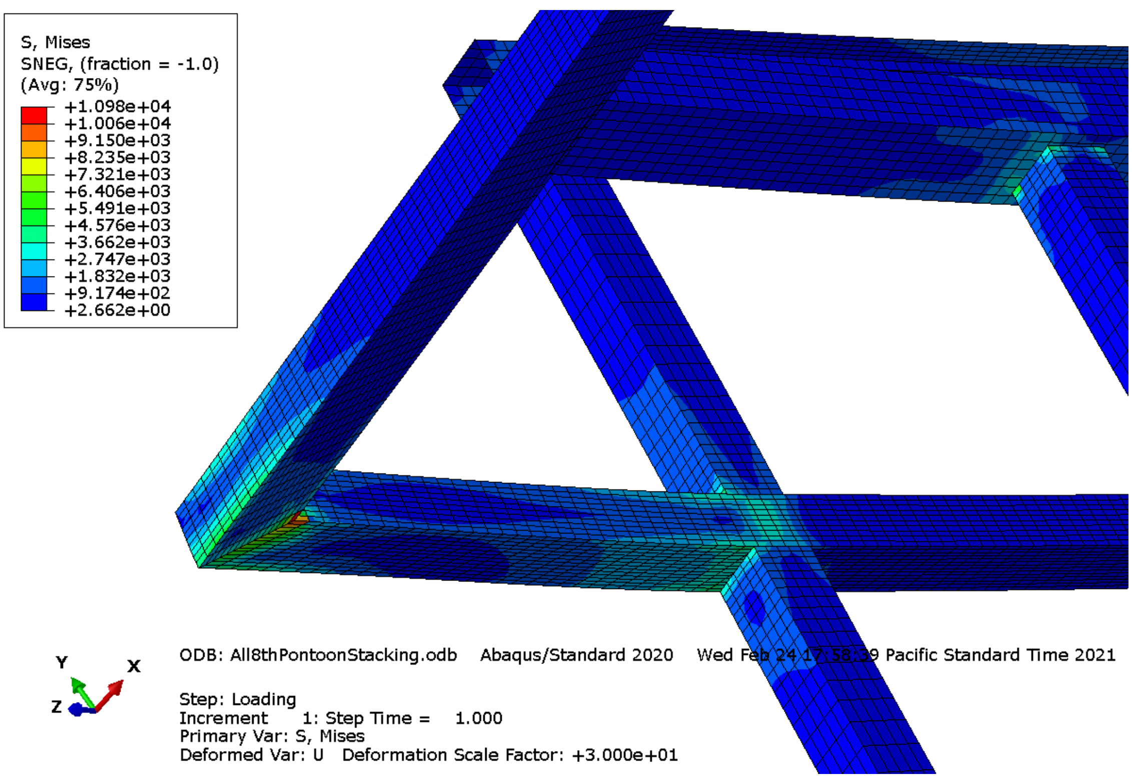


Figure 37. Pontoon Stacking load case stress results zoomed in on the area of highest stress.

Table 7. Loading Factors of Safety.

Loading Case	Safety Factor - Yield	Safety Factor - Ultimate
Lifting	2.6	4.1
Ground Stacking	2.0	3.2
Pontoon Stacking	2.2	3.5

One issue that we had with analyzing the results of our FEA and determining safety factors was in determining which values should be used for the yield and ultimate strength of the aluminum. Since all high stress areas occurred around welds, we had to consider the strength knock-down of the Heat Affected Zone (HAZ) as well as the strength of the filler material. For the HAZ, we used an ultimate strength of 30ksi and a yield strength of 19ksi, based on a data sheet for 5356 filler wire [21].

Because we connected frame members with tied constraints in ABAQUS and did not model the fillet created by welding corners, the mises stresses of tied corner elements were artificially higher than elements around them. To account for this when calculating the loading case safety factors, we took stress values from elements around the high stress locations and used the average. Stress values used and safety factor calculations can be found in Appendix O: FEA Parameters and Loading Cases.

Based on our analysis, we suggest that the operators stack the rafts a maximum of four high if the bottom raft frame is supported and the pontoons do not contact the ground. The limiting factors for this case are the stability and feasibility of stacking higher, and the strength of the upper deck welds. Although we did not design it, a structure which supported the bottom frame and raised the pontoons off the ground would allow LLNL to stack rafts higher without deflating the bottom pontoons. If the bottom pontoons are in contact with the ground, the rafts stacks should be a maximum of two high. This is primarily due to the load rating of the pontoons but also the strength of heat affected zone (HAZ) around the corner groove welds on the main deck.

5.1.3 Motor Mount Subassembly

The design for the motor attachment subassembly centered around the desired movement of the raft. The current LLNL raft is only able to move forward, so for our design we wanted to achieve forward and reverse movement. In addition to achieving forward and reverse motion, this motor attachment must accommodate the deployment, stacking, and storage of the rafts.

To move the raft, we needed to determine a method of propulsion. Our background research in 2.4 Propulsion Method Research yielded some potential propulsion options. We conducted further research to make sure that we found the right choice for our design. Table 8 tabulates the results from our research.

Table 8. Potential propulsion product options.

Manufacturer	Product Name	Type	Cost ($)	Size (in)	Thrust Output (lbf)
Blue Robotics	T200	Shrouded Thruster	$179.00	3	11.6
Torqeedo	Ultralight 403	Unshrouded Trolling Motor	$1,799.00	8	33
Tecnadyne	Model 550	Unshrouded Thruster	Quote	6	15
Blue Trail Engineering	THR-100X	Unshrouded Thruster	$1,900.00	8	6.75
Newport Vessels	Kayak Trolling Motor	Unshrouded Trolling Motor	$139.00	NA	36
Minn Kota	Riptide	Unshrouded Trolling Motor	$749.99	NA	55

These products range in cost from around $200 to almost $2000 each. With our budget, we were looking for something that would overcome the drag on the raft at the given speed, while keeping the costs as low as possible. We performed preliminary drag calculations on the raft to estimate the power requirements needed to achieve the speed requirement.

The first step in determining the drag on the raft was to consider the types of drag that act on the raft. There are four main sources of drag on our raft: skin friction drag, pressure drag underwater, pressure drag above water, and the drag due to created wake. We have modeled each of these forces using the drag equation, which states that the force due to drag is proportional to the product of the density of the fluid, the area over which the drag acts, and the velocity of the flow. Appendix P: Thruster Calculation Memo is a memo written to the project sponsors justifying thruster selection, including the drag analysis. Appendix Q: Thruster Calculation Excel Work is the Excel workbook providing reference to the values used to quickly solve for air and water speed for any given maximum thrust.

While Table 8 includes a variety of motors and thrusters to choose from, we have decided to use the T200 shrouded thruster from Blue Robotics. Even though the voltage that we will be using reduces its forward thrust from 12 to 8 pounds-force, the thruster offers many advantages for our design. The small dimensions make them easier to accommodate in a size constrained design, and since they are off-the-shelf components, LLNL can easily replace them should they become damaged. Additionally, they had the highest thrust to weight ratio at the lowest cost. This combination of factors makes these thrusters the best choice for our design. The drag calculation worksheet suggests that the use of four of these thrusters will allow a top speed of more than 8 feet per second, which is 1.6 times greater than required. While this is a good starting point, it does come with multiple assumptions and simplifications that may reduce the ability of the drag calculations to predict the performance of the final design. As such, we will perform speed testing to ensure that the design meets this specification.

After the preliminary design review and thruster selection, we began ideating further on the motor attachment. Through this ideation, multiple potential ideas arose such as a vertical sliding mechanism, a four-bar linkage mechanism, a bow-to-stern swinging catch-latch mechanism and an outward swinging arm mechanism. Through various discussions regarding the feasibility and functionality of these options, we decided to incorporate the swinging latch into our design. Figure 38 shows the initial design for the motor attachment.

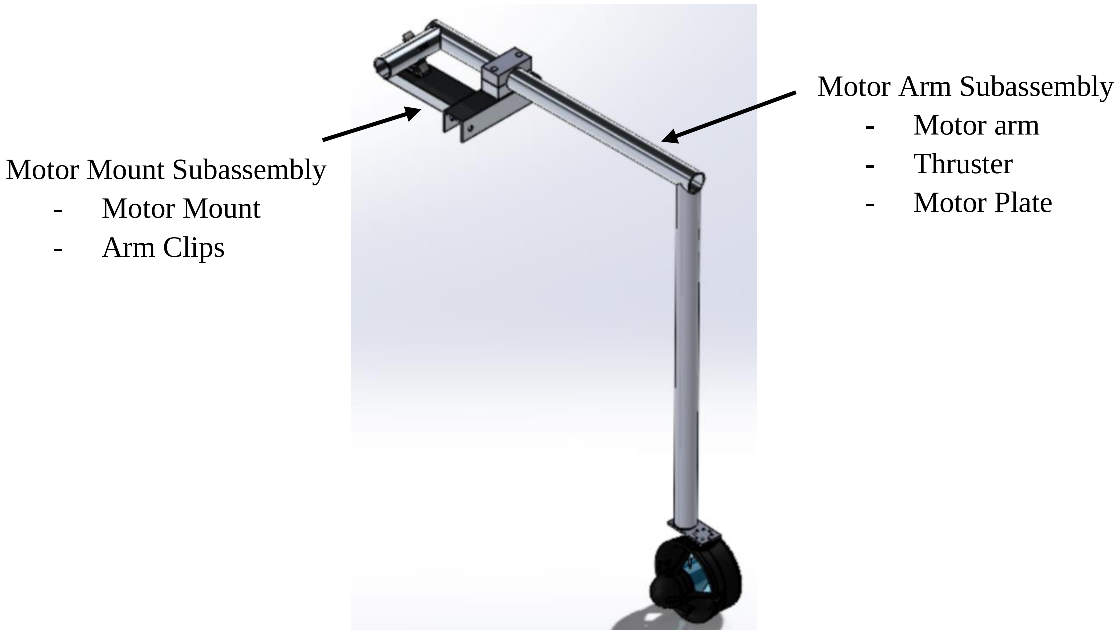


Figure 38. Initial motor attachment design.

This design keeps the motor arm in place while running in forward or reverse using a holder at one end of the arm. The idea is that the clip keeps the motor in place during operation but will allow the arm to break free and rotate into a storage position—which would occur when operators lower the raft onto the deck. A key assumption in this design is that the clip can perform as intended in both loading cases. We built a structural prototype as a test bed to allow testing of multiple different clip and holders. Testing involved 4 different clips and holders between two tube diameters of 1 and 0.75 inches. Figure 39 depicts the structural prototype and test set up.

Figure 39. Structural prototype to test varying clips.

Because we designed the rafts to stack, the clearance between stacked rafts is a design constraint on the motor mounts. To ensure our motor attachment design does not interfere with the raft above, we used a cross section of the stacked pontoon, held at the correct height to monitor interference. In Figure 40, the structural prototype setup is shown with the pontoon modeled out of carboard.

Figure 40. Structural prototype, with the pontoon silhouette to monitor interference.

The force the clip experiences when the raft is in operation is directly related to the force produced from the thruster. The T200 Blue robotics thruster produces a nominal thrust of 8 pounds in the forwards direction and 6 pounds of thrust in the reverse direction. We were not concerned with the forward propulsion since the clip would act as a stop block due to the nature of the rotation of the motor. We were mainly concerned with the capability of the clip withstanding the reverse thrust of 6 pounds. This reverse thrust force from the motor creates a moment along the axis of rotation that translates into an upward force on the clip. The goal of the structural prototype was to record the force at which the motor arm would break free from the clip. To simulate the thrust of the motor, we connected a weighing scale at the location of the thruster and pulled on the scale. We recorded the amount of motor force each clip withstood before breaking free and recorded the results in Table 9.

Table 9. Allowable motor force for each clip.

Clip	1" Diameter	3/4" Diameter
Sea Choice	3.31 lb.	2.57 lb.
Sea Choice (x2)	5.28 lb.	-
Amarine	5.89 lb.	3.07 lb.
Amarine (x2)	10.04 lb.	3.71 lb.
McMaster S.S clip (x2)	-	4.95 lb.
Cabinet Latch	12.17 lb.	-

From the results, we see that the cabinet latch was able to withstand the most force, however, given the tight space in between stacked pontoons, the cabinet latch would be too big to accommodate our design needs. Therefore, we decided to move forward with two Amarine clips on 1 inch diameter tubing because this combination was able to withstand roughly 10 pounds-force before it became unclipped, resulting in an estimated safety factor of 1.67.

While this structural prototype helped decide which clip and tube diameter would be best, it also provided insight on how the design moves and reacts. We observed that the single point of contact from the holder was not as secure as we anticipated and resulted in an unsteady motor arm. Additionally, we noticed that the geometry of our initial vertical arm design would not enable the swinging storage movement we desired. Similarly, we agreed that the motor should not take the load of the vertical force needed to enter storage mode. Based on these findings, we included a second holder onto the structural prototype and found that it was more secure and stable, and translated the moment from the force better. Figure 41 shows the structural prototype with two holders.

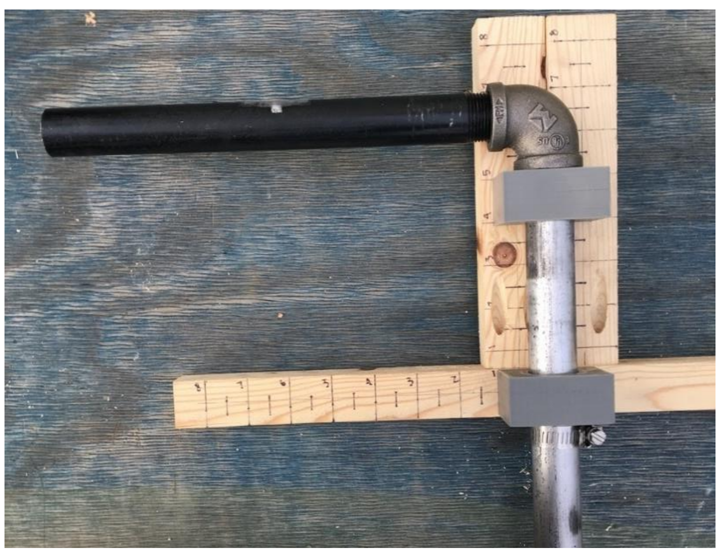


Figure 41. Structural prototype with two holders.

We also concluded that the motor arm should not be vertically in line with the axis of rotation and as a result, decided that an angled arm at 15 degrees would be ideal. With this angled motor arm, the design would both allow for clearance between stacked rafts and be able to enter storage mode. We also agreed to extend the angled arm past the bottom of the motor to act as the point of contact for the vertical storage force. Figure 42 shows the final design for the motor attachment.

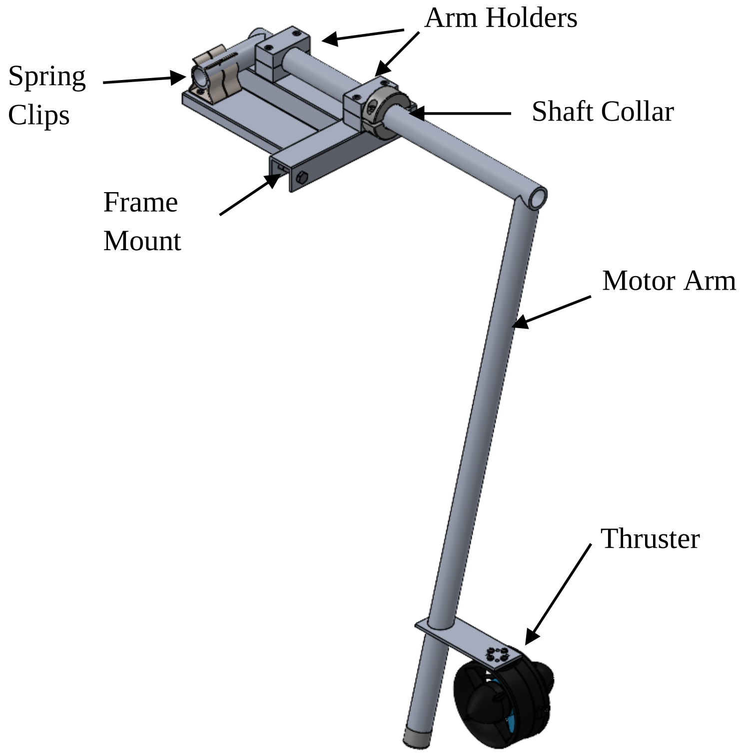


Figure 42. Final Design for motor mount attachment.

The final motor attachment material is primarily 6061-T6 aluminum, comprised of two main components: the motor mount and the motor arm. The motor mount consists of five components, and it attached to the raft frame with two bolts. We wanted the motor attachment placement to be flexible, and this drove the simple installation method. These motor attachments can be installed at many positions on the port or starboard side of the frame. On the motor mount, we have specified two aluminum channels, welded perpendicular to the frame mounting channel. On the ends of these extensions are the two Amarine clips and one of the arm holders—the other arm holder is on the frame mount channel itself. The holders consist of a top and bottom part, held together with socket head screws. The hole created between the top and bottom parts provides enough clearance to align an allow free rotation of the motor arm. We outsourced manufacturing of the holders due to their complex nature and our limited resources. Figure 43 shows the motor mount assembly portion of the motor attachment.

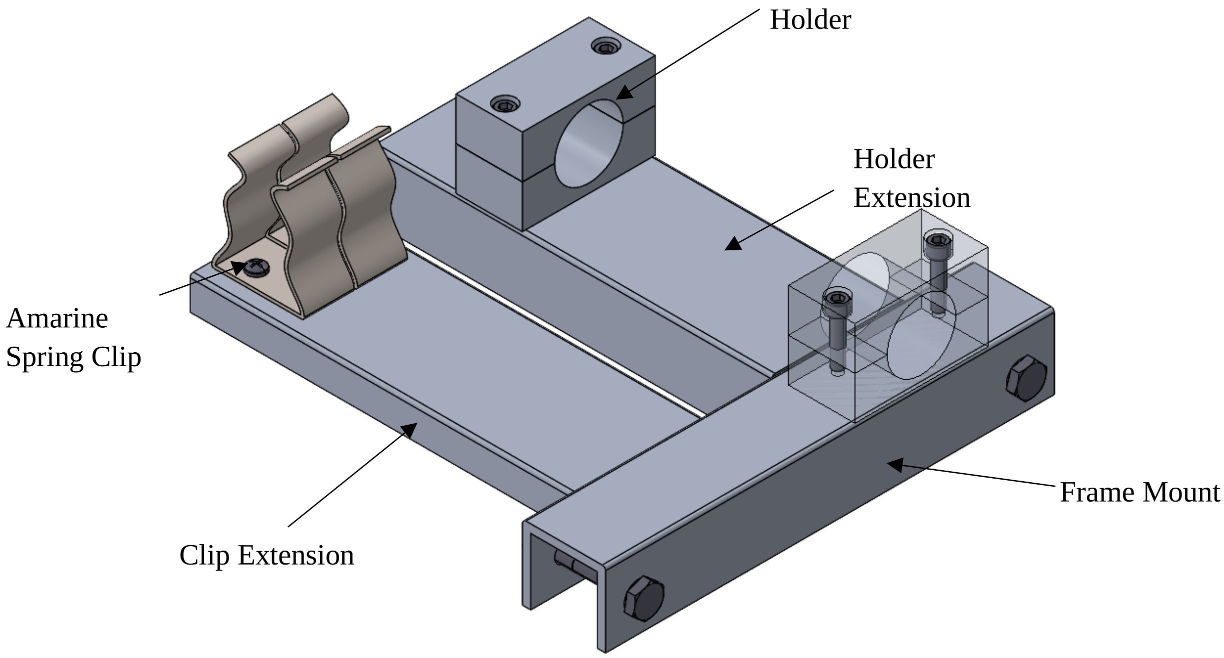


Figure 43. Motor mount subassembly.

The other component in the motor attachment is the motor arm, which consists of three aluminum tubes: a shaft collar, a motor arm plate, and the T200 thruster. Both the short end of the motor arm and the shaft collar act as stop blocks and constrains axial motion along the middle arm. This eliminates the need to align the motor arm manually into the clip and instead will simply require the user to pull on the angled tube to force the motor arm back into the clip. The tubing and the motor arm plate are welded together; the shaft collar clamps onto the tubing directly. The motor arm plate includes eight evenly spaced holes, in a circular pattern. This allows the option to install the thruster at 45 degrees. While our implementation does not include orienting the thrusters at 45 degrees, we wanted to allow this option for future testing and modifications by LLNL. The model in Figure 44 shows the complete motor arm subassembly.

Figure 44. Motor arm subassembly.

These two components make up our completed motor attachment. All together, we believe this design will achieve the desired forward and reverse movement, accommodate stacking and allow storage, as shown in Figure 45.

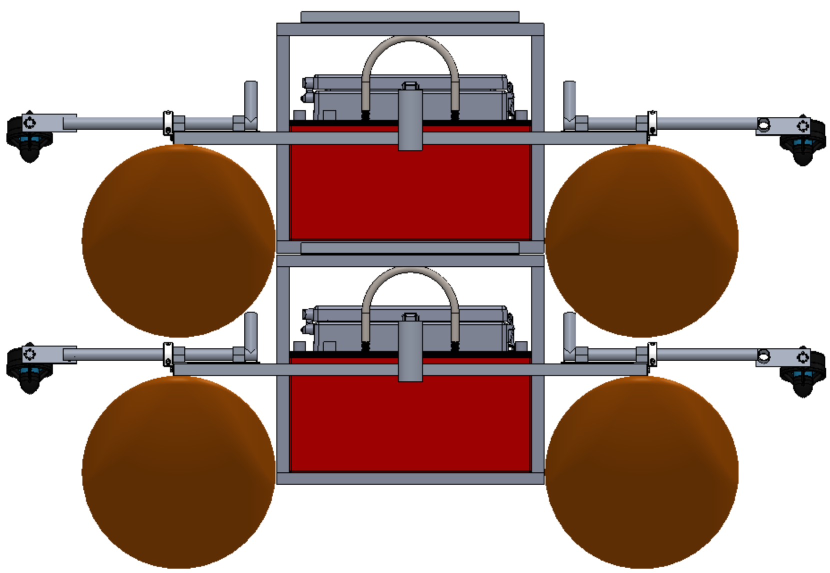


Figure 45. Motor attachment displaying stacking and storing capabilities.

While we have installed four motor attachments onto our final design, we believe the modular and compact nature of this design will allow easy customization of the motor attachments for future designs.

5.1.4 Battery and Payload Subassembly

The battery and payload are the heart of the design, as without these components the raft can neither move nor collect research data. These two components are based heavily off the current solution that LLNL uses since the products are reliable and the suppliers are well known.

For the battery, we chose to use the same battery supplier that LLNL currently uses. Lithionics Battery is a company that provides plug-and-play batteries for marine and recreational vehicles with built-in-battery management systems. The connectors are standard on their batteries, and this integration with the current LLNL components will reduce the cost of electrical cables and connections.

After choosing the supplier of the battery, we needed to decide on a nominal capacity and voltage for the battery. The current batteries are 25.6 volts with a capacity of 200 amp-hours each. Our chosen motors are rated for a max. of 20 volts, and LLNL's other electronics run on 12 volts, so we wanted a 12-volt battery with more amp-hours than their current solution. Lithionics has a battery that achieves these specifications, so we opted to design around that battery. The GTX12V315A-E2107-CS200 battery from Lithionics has a nominal 12.8 volt with 315 amp-hours, for a total life that is about 80% of the current raft. While this is a larger discrepancy than we would like, we believe that the reduced weight and drag of the raft, as well as its efficient motors, will allow it to achieve similar mission times. Figure 46 shows the selected battery.

Figure 46. Chosen Lithionics battery, model GTX12V315A-E2107-CS200. [22]

Based on thruster data published on the Blue Robotics website [18], and assuming all four motors are driving at constant full throttle, we calculate that the battery would last for 4.5 hours. At half power on all motors, that time increases to 13.8 hours. Our chosen battery is also only 67 pounds compared to the 135 pounds of the current batteries, and has dimensions better suited to fitting in our frame.

LLNL’s current raft uses an aluminum Hoffman Box; Hoffman is a large manufacturer of NEMA enclosures for both indoor and outdoor use. The Hoffman box allows LLNL to keep instrumentation dry, safe, and secure while also having easy access inside for troubleshooting. Therefore, it made sense to stick with the same brand as they are currently using. The components that we need to include in the box heavily drive the box dimensions. The selected box is the A20H1612GQRLP fiberglass box with a rough outer dimension of 20 by 16 by 12 inches. Figure 47 shows a SolidWorks model of the Hoffman box from their website. We chose this box because it meets the required space volume that Mr. Nyholm and Mr. Fuller requested, while being short enough to allow for stacking of the rafts. An additional benefit of a fiberglass box is we can mount radio antennas within the box instead of requiring through box connectors for these components.

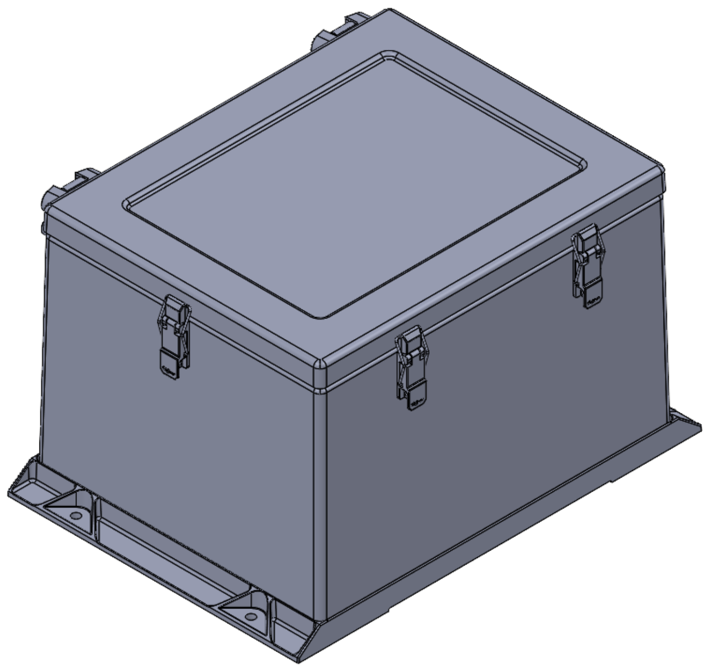


Figure 47. SolidWorks model for our selected payload box.

Initial design work we primarily focused on mechanical systems, but once the payload box had been selected, we began to create a wiring diagram for the raft. This included the major electrical components like the core control board, GPS, and radios which were provided by LLNL. Additional miscellaneous electrical components to distribute power were included to complete the diagram. These components include a main power switch, a main fuse, a bus bar for distributing power to the motor controllers, and the waterproof connectors that go through the payload box. Lawrence Livermore Engineers worked closely with us checking our wiring diagrams and ensured that our electronics system interfaced properly with their software. Our process started by looking at wiring diagrams of LLNL’s existing rafts and recreating the sections of them that would stay the same, like the core board and its connections to the radio and compass. We then added components and connections for the ESCs and power distribution. Our final wiring diagram is found in Appendix U: Wiring Diagram. Once we had a wiring diagram, we moved on to specifying individual components.

Since our ESCs are vastly different from the motor controllers LLNL currently uses, adjustments had to be made to LLNL's core board to connect and send the proper signals to them. Instead of designing this connection ourselves, Mr. Fuller designed and tested a small PCB that translates between the two systems, seen in Figure 48. This expansion board attaches to a slot in the core board and has four pin connectors to which the thruster ESCs directly plug. This allowed us to focus primarily on power distribution to the system rather than accommodating signals.

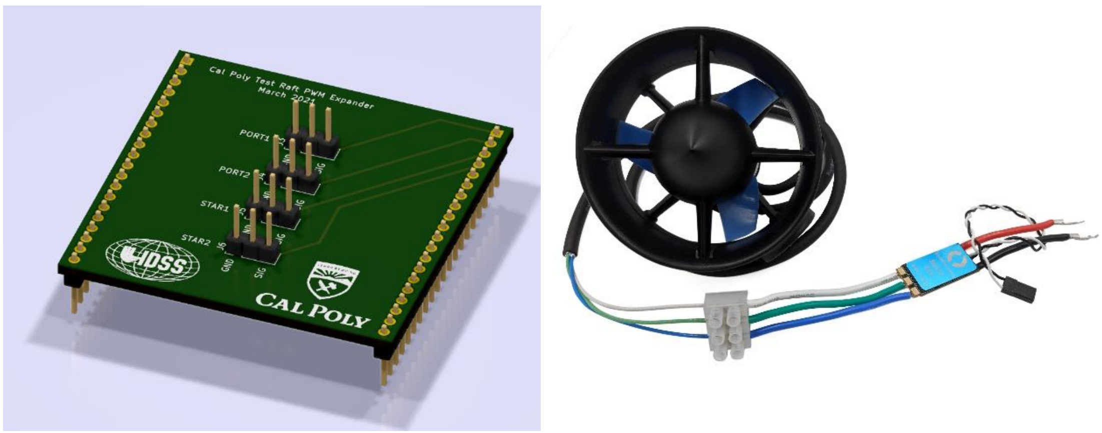


Figure 48. ESC expansion board designed by Sam Fuller (left) and Blue Robotics thruster with ESC (right) [18].

The next step in specifying electrical components was to determine the max amperage the system would experience. Using data on the Blue Robotics' website for max current draw at our system voltage, we found that our system would need to support around 70A to power four thrusters and raft control electronics [18]. All components in the power distribution system needed to support at least 100A to add factors of safety. We specified 6AWG cables to carry the full current from the battery based on specifications on the cable manufacturer's website [23].

To distribute power to the ESCs and control boards we chose to use bus bars since they would keep each system in parallel and provide equal voltage with varying current. The bus bars had to have at least 6 terminals, but we selected one with 10 terminals to allow for future expansion of the raft electrical system. The studs on the bus bars were sized to fit existing power connectors on the ESCs, and the bus bar itself has a current rating of 150A at 12V [24]. Figure 49 shows the bus bar used in our payload box.

Figure 49. Selected bus bar for power distribution.

To reduce the number of parts we would have to purchase, the primary power switch we specified for the system was the same as one LLNL already uses. The Blue Sea Systems switch had a high enough voltage an amperage rating for our system and could be sent to us directly from LLNL with other electrical components we received from them.

At the suggestion of Lawrence Livermore Engineers, we included and specified a fuse to prevent overcurrent and damage to the system. The fuse inserts in the design after the main power switch but before the bus bar on the positive end of the circuit. We used the website Digikey to search for available fuses and fuse holders and found that only automotive fuses had current ratings high enough to support our system. We specified a 100A bolt down fuse from Littelfuse Inc. that sits in a holder attached to the main power cables through studs. Since the fuse and holder are a standard size, the fuse is easily with others of higher or lower current ratings if needed. The fuse also featured a clear housing to easily diagnose when the fuse is blow. Figure 50 shows the selected fuse and fuse holder.

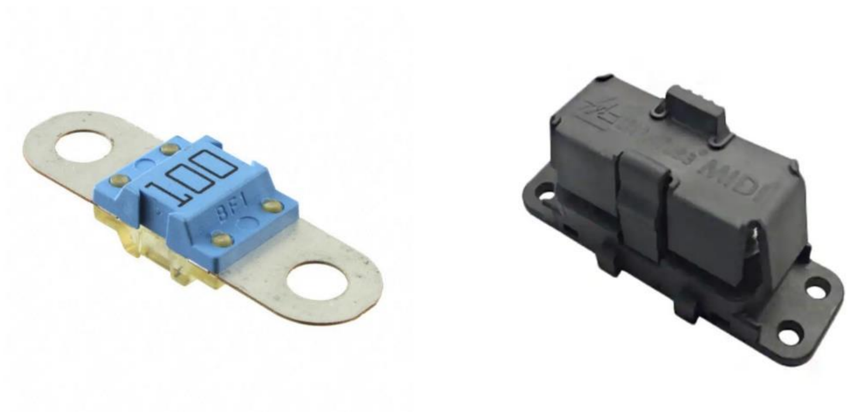


Figure 50. Selected fuse and fuse holder for the raft electrical system.

All these electronics are contained within the payload box, aside from the switch and the battery. A waterproof connector allows power to enter the box from the battery. Four other connectors pass signals from the ESCs in the box through to the thruster cables and thrusters outside the box. The raft will be controlled using a radio connected to a laptop with LLNL control software. That master radio sends control signals to the radio within the payload box and receives diagnostic data back from the raft.

5.1.5 Light Pole Subassembly

One of the components that LLNL requires that we accommodate on the new design is a flash head that helps locate the raft in the dark. To make sure that the main ship can visually locate the raft from far away, a flash head is located 7 feet above the water line. We plan to support the flash head on a fiberglass pole that is 1.5 inches in diameter, so that it mates with the flash head. This light pole will fit into a collar on the frame that has an inner diameter of 1.75 inches and a 0.125-inch wall thickness. The pole connects to the collar with two wire-locking clevis pins, to fix the light pole in place while the raft is on the water. Figure 51 shows the light pole in its upright position, with the clevis pins securing it to the frame.

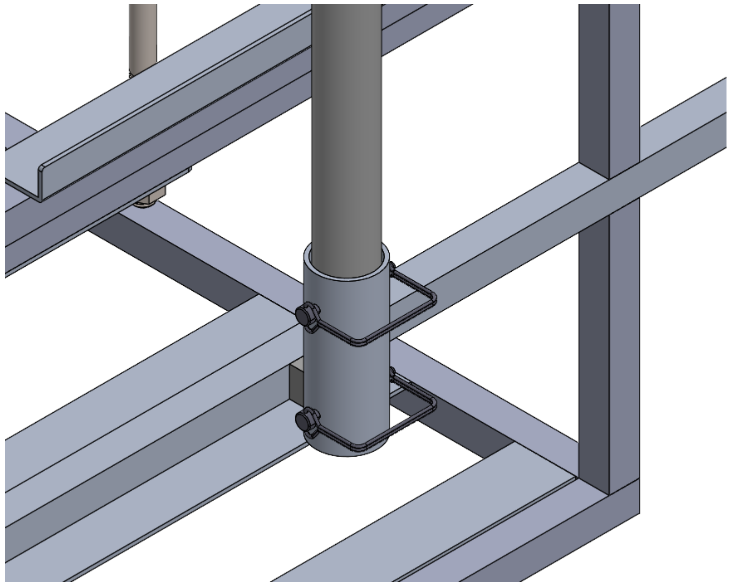


Figure 51. Light pole in its upright position and connected to the frame.

When stacking the raft for transport, we have designed the frame to accommodate storage of the pole when not in use, although there is a stacking configuration – bow stacked on stern – that allows the light pole to remain in its upright position. To accommodate this storage, we have added clips to the underside of the middle frame level, at both the bow and the stern of the raft. This is not a permanent storage solution for the pole, as the pole is longer than the frame itself, but while the frame has the pontoons attached and inflated, the pole can rest in this unused space immediately before deployment and after retrieval. Figure 52 shows the location of one of these clips, in relation to the light pole collar.

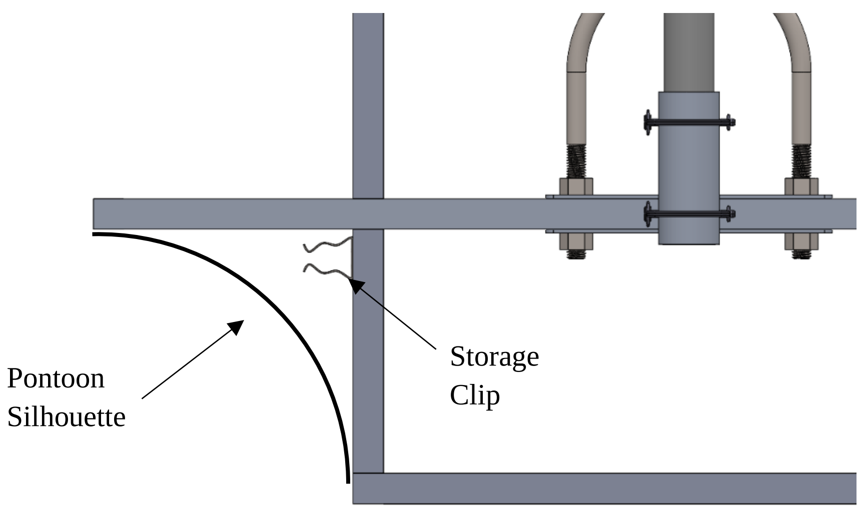


Figure 52. Light pole clips for temporary storage on the raft.

5.1.6 Flotation Subassembly

Two custom pontoons will provide the flotation for the raft. The manufacturer that LLNL has used in the past for their pontoons is Maravia; they are known for producing durable and reliable rubber products. We considered various manufacturers and due to the custom nature of our design and the previously established relationship with Maravia, we ordered pontoons from them. Maravia uses a company-specific Class VI base fabric and encapsulates the pontoons with a seamless coating of liquid urethane [25]. The selected pontoons are 8 feet in length with a diameter of 16 inches. Each pontoon will have two separate air chambers to increase the reliability of the entire craft if the rubber were to encounter a puncture. The recommended capacity of the tubes is approximately 500 pounds which limits the stacking of the rafts at two high if the pontoons are supporting both full crafts. The valves for the air chambers are located on the interior of the tubes in easily accessible locations to maximize functionality. On the outside of each pontoon there will be two handles allowing four operators to manually carry the craft. Operators should only use the handles to move the raft when carrying one at a time due to overall weight of approximately 200 pounds. Additionally, each pontoon will have 6 D-Ring attachment points. There are two located on either side of the pontoon in the straight section and one on each end of the tube. Figure 53 provides a sketch of the specific pontoons that we have selected for the prototype for reference on all dimensions and features.

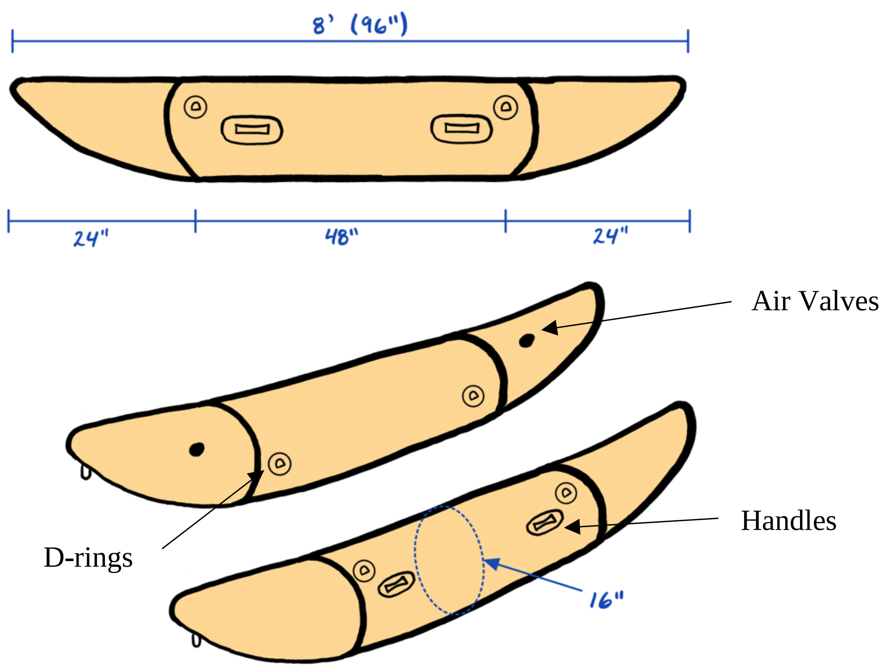


Figure 53. Schematic of the custom designed pontoons.

The pontoons will secure to the frame using Northwestern River Supply (NRS) 1-inch straps, looped through the frame and the D-Rings on the straight section. Four straps will secure the pontoons on each side to increase the reliability of the connection. Appendix L: Indented Bill of Materials provides the reference material for the pontoons and straps.

5.2 Safety, Maintenance, and Repair

To make sure that our final design is as safe as possible and satisfies our customers, we undertook two main safety reviews. The first of these was a Failure Modes and Effects Analysis (FMEA), which helped us consider all the ways the design might fail to satisfy end uses, how these failures might come about, the results of these failures. The second was to complete a Design Hazard Checklist, which lists common hazards and invites planning on how to mitigate the risk due to those hazards.

5.2.1 FMEA

FMEA is a robust tool that helps design teams focus their improvement efforts on areas of a design that have a high likelihood of severe failure that also have a low chance of detection before the product reaches the end user. For our project, these failures manifest in a variety of ways, as there are many components on our raft that could cause unsatisfactory performance to the end user.

We broke the full design down into systems and then further into system functions. For each system function, we evaluated a failure mode and resulting effects to analyze the greatest concern for potential failure in the design. The full design tree breakdown for the FMEA process is in Appendix R: FMEA Design Trees.

Following the full system breakdown, we prioritized each system function based off severity, occurrence, and detection. Appendix S: FMEA Table shows the data table with the results of this process, highlighting three particular high risk system failure modes. The two highest priority failure modes were related to the payload box, through either support members failure or intrusion of water due to the ocean environment. Both failures result in the inability of components to operation inside the payload box. Loss of these functions not only terminates the data collection process but also thruster control. The actions in place to minimize the possibility of these failures are testing and evaluation, of both the support structure and the sealant material. The third particularly high-risk system failure mode was a tear in the floatation. This failure mode has the potential to result in whole or partial submersion. Either case risks damage or loss of equipment and we intend to implement measures to minimize the occurrence of this failure. We provide inspection, maintenance, and repair procedures with the final design documentation. Additionally, each pontoon has two air chambers to increase the flotation redundancy such that a puncture in any one chamber will not result in an immediate full submergence of the raft. The remaining medium risk failure modes have recommended preventative actions detailed in the FMEA table and all procedures and warnings are provided in the User Manual.

5.2.2 Design Hazard Checklist

The current design inherently presents hazards due to the mechanical and electrical elements as well as the physical scale of the structure. We must mitigate and manage potential harm to operators and other variables near or in contact with the raft, such that operator injury or property damage is avoidable. The primary hazard stems from the use of electricity near the presence of water. Being that the boat will operate in a wet environment and needs electrical power to function this hazard is unavoidable. The measures proposed to limit the potential damage and injury involve proper training and procedures, warning labels, and waterproof coating. All three of these corrective actions when used simultaneously greatly reduce the hazard but does not eliminate it. Caution must always be taken when the electrical system is live in the wet environment.

The second largest hazard related to this design is due to the size and weight of the structure. The overall footprint is approximately 8 by 5 feet and weighs 200 pounds. Mainly, a crane transports the raft in the air to move it when it is not in the water. The anticipated method of transport will happen by any one or combination of the following methods: manual human force, crane, or forklift. Damage or injury can result if operators drop the craft while carrying it.

We will provide protocols and safe practices to minimize these hazards as much as possible, but they will still be present. These two hazards have the potential to cause the most damage and harm but there are others with less severe consequences. The complete hazard evaluation for this design is in Appendix K: Design Hazard Checklist, which explicitly defines all hazards and risk with their respective corrective actions.

With respect to maintenance and repair, these procedures are mainly beyond the scope of the project. While we can suggest reasonable timelines to replace components, our goal is to integrate the design into the procedures that LLNL already has in place. Therefore, this raft should maintain a similar inspection regime and repair procedure as the current rafts. Our design has inherent pinch points and safety concerns when assembling and disassembling which, while we have attempted to avoid, are paramount to raft operation. To help reduce the risk of these hazards, we have included warnings in the User Manual.

5.3 Cost Estimation

Estimates for material and resource costs are crucial for the success of both the prototype build and the final design. We have estimated the cost of both. The primary difference in estimated price is due to the smaller battery that we are using on the prototype compared to the final design. During detailed design, we estimated the cost of the final design to be slightly under $10,000 with the prototype coming in slightly over $5,700. Table 10 shows the full breakdown of costs as of March 22nd, 2021, and the estimated future costs.

Table 10. Full prototype build cost analysis with ordered and estimated components.

Prototype Build Cost Analysis	
Item	**Cost**
Preliminary Testing	$130.89
Pontoons	$2089.00
Thrusters and Motor Controllers	$906.68
Frame Assembly	$454.80
Battery and Waterproof Case*	$200.00
NRS 1” Straps*	$89.76
4 Motor Mount Assemblies*	$300.00
Electronics*	$150.00
Hoffman Dry Box*	$1400.00
Total	**$5721.13**

*Parts that have not been ordered but are estimated intended use products. The price includes shipping and tax.

The total cost for the prototype will directly correlate with the material cost as the design team will perform almost all manufacturing. The total estimated cost for the prototype is approximately $5,700 which we can reduce by $1,400 with the substitution of a different payload box. We estimate final design cost to be near the final budget of $15,000 once we consider the cost of manufacture and the addition of a higher capacity battery. Since the frame and motor mount assemblies are custom welded assemblies, they will carry significant manufacturing costs that we are not able to estimate. Select electrical components for raft control, data collection and the flash pole head have also not been factored into this cost estimate, since they are LLNL components that are outside of our scope and intended to be carried over from current rafts.

5.4 Suggested Design Changes

After manufacturing the prototype, we found a couple of elements in the design that may require adjustment. This section outlines these adjustments to the final design.

Firstly, the proposed location of the light pole clips is impractical. During our assembly and disassembly tests, we found it too difficult to store and retrieve the pole from this location. We moved the clips to under the upper deck and found a space that fits the pole nicely. Unfortunately, storage in this position prevents the payload box from fully opening, but this may or may not have an impact on the deployment process. Since they are easily moved, we recommend LLNL reconsider clip placement to work with their current deployment procedures. Figure 54 shows our new placement of the storage clips.

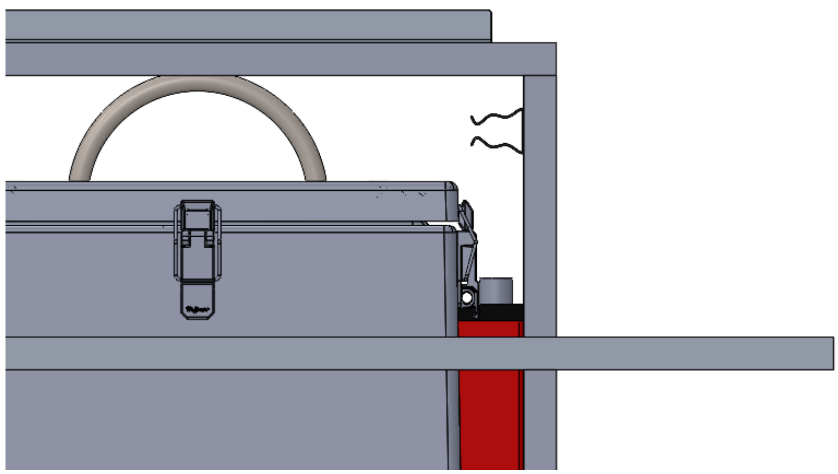


Figure 54. New placement of the flash pole storage clips.

Additionally, our repeated installation and removal of the motor arms resulted in minor damage on one arm to the thruster extensions to which the thrusters mount. This could be solved by increasing the thickness of the plate from which these pieces were cut, thus increasing the stiffness and preventing this damage from occurring in the future.

After examining the behavior of the motor mounts when clipping or unclipping the motor arm, we think the motor mount design would benefit if the overall design were more rigid. While this is the case, further design iterations should also be mindful of the limited space surrounding the motor mount when another raft is stacked on top. Another consideration for the motor mount includes deepening and countersinking the tapped holes on the bottom holder. This would make it easier for manufacturing the tapped holes as well as make assembly between the top and bottom holder quicker.

Looking at the functionality of the motor arms, we noticed that there was interference between the motor arm and the pontoon. This is because, when set on the ground, the inflated pontoons tend to compress and push against the motor arm. To remedy this, we recommend extending the middle tube of the motor arm, 112.42 Arm B, at least one inch.

When considering the strength of some of the frame components, we suggest that c-channels be used in place of the angle aluminum for the payload and battery supports on the lower deck. We believe that a c-channel would add greater support as well as add increase surface area for welding. In addition to this, we recommend exploring adding extra support, such as a guide or hoop, onto the top of the frame to help restrict the movement of the light pole and alleviate the stress on the light pole holder. We also recommend using connectors between the inside and outside of the payload box instead of cable glands as they are less reliable and more complicated to use for wiring assembly.

Some minor changes we think would be beneficial to the design include using Phillips head screws for all components of the motor attachment and limiting contact of dissimilar metals—this is present with our aluminum components and their respective steel fasteners.

6.0 Manufacturing

The manufacturing chapter highlights the build process that we went through to produce the prototype. All the manufacturing to make the frame and motor mount assemblies took place in the Cal Poly machine shops. All materials used in the final design build are in Appendix L: Indented Bill of Materials and the drawings for these custom parts and assemblies are in Appendix M: Drawing Package. Additionally, the detailed manufacturing procedures for all custom or modified components are in Appendix T: Manufacturing Plan. As previously mentioned, we made some modifications to the prototype to ensure our resources could achieve a functional and testable build. Many of the parts in the prototype were identical to the final design and we have detailed any variations within this section.

6.1 Changes to Final Design for Manufacturing

Our analysis supports the final design that we have modeled and drawn. However, the design heavily relies on welding to manufacture both the frame and the motor attachments. While we would have liked to manufacture the raft as designed, critical self-reflection indicated that while we could practice and acquire the skills necessary to weld, we would not have the time. Under advising from more experienced welders, we determined that the team skill level and available manufacturing time were not enough to feasibly complete our frame as designed. COVID-19 precaution limited the length and availability of shop time in general, especially when consistency with welding equipment and settings is a large component of success.

To reduce the amount of welding that we need to perform on the prototype, we chose to replace around half of the frame welds with brackets and fasteners. We chose to keep welds between members within the upper, middle, and lower frame decks, but used brackets to connect the decks to the vertical supports holding them together. Figure 55 shows a SolidWorks model of our modified frame with brackets. Retaining some welds increased the strength of the frame, give us the opportunity to practice and improve our welding skills, and reduced the time we had to spend designing the brackets. We also wanted to avoid adding fasteners in areas where the frame contacted the pontoons. We do not recommend using brackets for the final design due to their decreased strength, increased weight, and high part and fastener count. Using brackets instead of fully welding the frame should not negatively affect our testing since our testing is focused on overall raft performance rather than frame strength. We will also not be testing under the high load conditions of stacking and lifting for which the fully welded frame is designed.

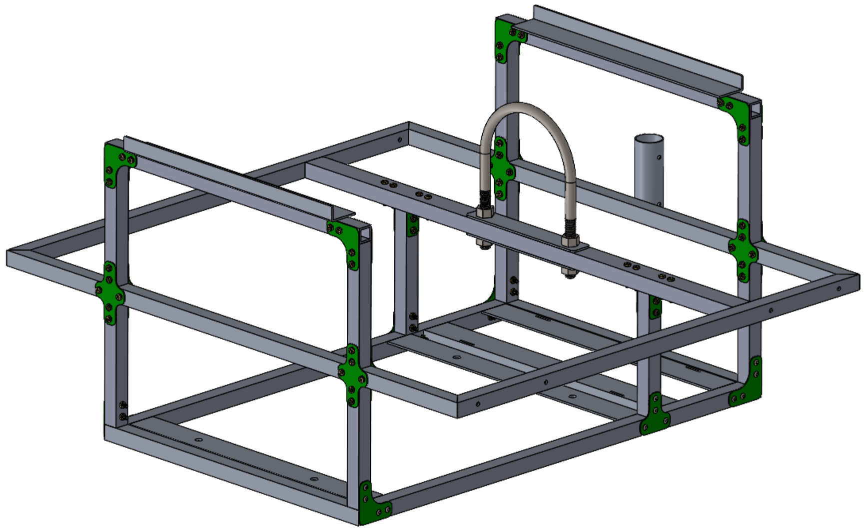


Figure 55. Modified frame for prototype with brackets and fasteners in green.

Finally, we wanted to reduce the cost and quantity of materials that we needed to procure, and so decided to replace the angle iron on the lower and upper decks with a smaller size, which was more readily available and cheaper. We used 1x1 inch angle iron as opposed to 1x2 inch angle iron because obtaining the latter would either be significantly more expensive or involve machining down 2x2 inch angle iron, which would stress our already limited manufacturing time.

Additionally, we substituted the specified Lithionics battery with a smaller, and significantly cheaper, lead acid marine battery. The increased cost of the Lithionics battery is due to its capacity and waterproofing standards which were not critical to our prototype testing. Our substitute must be water resistant, but its capacity and weatherproofing need not be to the standard of the intended battery.

6.2 Procurement

The frame consists of 6061-T6 square aluminum tube, angle stock, and off the shelf fasteners. For the frame members, we used stock sizes of 1-inch by 1-inch and 1-inch by 1.5-inch extruded aluminum tube, both with 0.125-inch wall thickness. We needed a minimum of 32 feet of 1 by 1 inch stock and 4 feet of 1 by 1.5-inch stock to manufacture the frame members. In addition, the altered design called for a minimum of 9 feet of aluminum angle stock with a size of 1-inch by 1-inch, again 0.125-inch thick. We also purchased fasteners for the lift point and flash pole; Appendix L: Indented Bill of Materials includes the specification sheets for these, and all other, purchased components. As mentioned, we adjusted the verification prototype design to make it easier to manufacture, and this required us to purchase 0.1-inch-thick sheet metal, for use in manufacturing water jetted brackets.

The motor attachment is a combination of off-the-shelf components and custom parts from raw material. Altogether, each motor attachment consists of twenty-one unique parts. Except for the thrusters, shaft collar and the clips, we purchased all the off the shelf parts from Fastenal—the details for the specific hardware and quantity are in the Appendix M: Drawing Package. We obtained the thrusters, shaft collars, and clips from Blue Robotics, McMaster-Carr, and Amarine, respectively. We have provided further specification details in the appendix.

The remaining components for the motor attachment were custom made from aluminum stock that required some form of cutting, machining, or welding. We got all raw material for these components through OnlineMetals. We purchased various sizes of 6032-T52 aluminum channel for the frame mount, holder extension, and clip extension, and choose 0.125-inch thick 6061-T6 aluminum sheet metal from which we water jetted the motor arm plates. While we originally intended to machine the holders ourselves from aluminum rectangle bar stock, we decided to outsource the eight holders through a rapid prototyping manufacturer called Xometry. The motor arms used a 1-inch outer diameter with a 0.125-inch wall thickness round aluminum tube. Required dimensions for these components are in Appendix M: Drawing Package.

To procure the payload box and accessories, we communicated with a local Hoffman vendor to finalize order details and arrange for pickup. The 12V lead acid battery used for testing was from Amazon, as well as cable glands and heat shrink tubing for waterproofing through-box connections and joints, the bus bars, and thruster cable extensions. We bought the battery cables in two 4-foot strands, along with the necessary crimped lug connectors, through Battery Cables USA. The fuse, fuse holder, and ESC cable terminals were purchased through DigiKey. Finally, fasteners and spacers for mounting electronics within the box were acquired through McMaster-Carr and Fastenal.

To acquire all these components, we worked mainly with one of Lawrence Livermore's technical coordinators, Brittany McKim. A typical order placement began with our team listing all desired components on an order form specific to our project. On this order form we listed items, descriptions, vendors, quantities, unit costs, and total cost. Once an order form was complete, we sent the form to Mr. Nyholm and Ms. McKim for approval. From there, Ms. McKim was responsible for placing and shipping orders to the machine shop address at Cal Poly.

We kept these order forms in our records to track the ongoing budget. With all components now ordered, the total budget for the duration of the project thus far is $5596.74, which we further explain in the cost analysis section.

6.3 Manufacturing Process

Appendix T: Manufacturing Plan outlines the manufacturing steps in detail for the final proposed build referencing Appendix M: Drawing Package for assembly and part specifics. The manufacturing process that took place for our prototype build varied slightly from what should take place for the final design; this section details those deviations. The three main manufactured subassemblies were the frame, motor attachment, and payload box.

6.3.1 Frame Manufacturing

The frame manufacturing began by cutting all the necessary members out of the tube and aluminum stock. Because of the complications and precision needed to weld aluminum, we cut all the interior support members (111.40, 111.5B, 111.5C) slightly oversized, so we could later trim them to fit perfectly in place. The only holes that we initially drilled were the bracket holes on the vertical riser bars and the drain holes in the main and lower deck. We drilled the rise bracket holes since they attached to other members using only brackets. The drain holes are necessary to prevent moisture accumulation on the interior of frame members but also provided venting for the hot air trapped in the frame when we were welding it. Figure 56 and Figure 57 display the completed frame members once all cutting was complete.

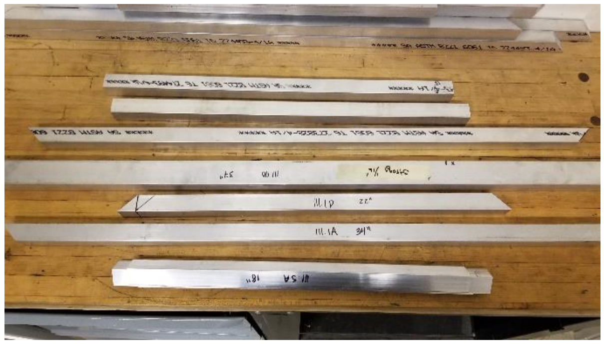


Figure 56. Cut and trimmed frame members, ready for welding.

Figure 57. Cut and trimmed riser bars, with bracket holes drilled.

We prepared all frame members for welding by applying a small bevel on the connecting edges to ensure full penetration. We cleaned all weld areas with a stainless-steel brush to remove the small aluminum oxide coating and wiped the weld area down with acetone immediately before welding to clean the surface.

The main and lower deck were first tack welded together to ensure that the members were square before completing the full welds. Both outer frames met tolerance and were less than 1 degree out of square. The fully welded main and lower deck are in Figure 58. At this point, we trimmed the support members down to their precise lengths and added the necessary mounting through holes. To ensure that welding was taking place as much as possible, and therefore keeping our manufacturing schedule on time, we welded the angle iron to the upper deck supports while drilling the mounting holes in the lower deck angle iron. This made better use of our already limited manufacturing time.

Figure 58. Partially welded main deck, left, and lower deck, right.

Once we finished the preparation on the support members, we welded them into their respective locations on the main and lower deck. This welding proved to be extremely difficult due to the compact nature of the design. For a professional welder, most of the welds would have been achievable but certain areas near the edges of lower deck were very difficult to reach. Concurrent to the welding of the support members, a shop tech cut the brackets for the frame from 0.1-inch aluminum sheet metal using an automated water jet. The brackets turned out well, but the edges needed to be deburred and the holes slightly enlarged before we used the pieces in the final assembly.

We anticipated that we would drill the holes for brackets and motor mounts using a drill press before the support members went in, but due to the proximity of support welds we could only add the holes after welding. Once we welded the members into the frame, we made use of a hand drill to add the holes for the brackets and the motor mounts in their respective locations. Some challenges arose as we completed this process since some of the bracket holes were located directly over aluminum angle and their welds. We swapped some of the bracket shapes and their orientation to overcome this problem. Figure 59 shows the completed main and lower decks, complete with all necessary support members. Synchronous to the drilling of the holes, we finished the final welding of the flash pole attachment. Figure 60 shows the completed flash pole mount. After finishing this component, the frame was ready for full assembly.

Figure 59. Completed main deck, left, and lower deck, right.

Figure 60. Completed flash pole mount.

6.3.2 Motor Attachment Manufacturing

The motor attachment consists of two subassemblies: the motor mount and the motor arm. The custom parts for the motor mount included three C-channels of varying sizes and the custom aluminum holders. The parts for the motor arm used round tubing and sheet metal. For the motor mounts, we began by cutting the C-channels to their respective lengths. Once this was complete, we used a manual mill to machine the frame mount channel down to its final height. From there, we drilled the holes for the fasteners at the specified locations. Figure 61 is a picture of the components laid out in their final configurations prior to welding.

Figure 61. Motor mount attachment layout prepped for welding.

Two of the crucial pieces of the motor mount are the bottom and top holders. Together, they make up the holder in which the motor arm will rotate such that it moves freely and precisely. The holders are a precise component, so we outsourced the manufacturing to a rapid prototyping vendor, Xometry. While Xometry was responsible for manufacturing the part, we tapped the holes in the final product. We used a tapping set to tap all blind holes for a total of sixteen #8-32 tapped holes. Since these were blind holes that extended only slightly past the bottom of the holder screw, chips would accumulate on the bottom during the tapping process. This causes a slight delay as we needed to remove chips to ensure the best quality threads. Some ways to remedy this would be to specify the tapped hole as a through hole or make the blind hole deeper. Regardless, once we tapped all the holders, they were prepared for welding onto the motor mount.

The motor arms followed a similar process. We began by cutting down Arms A, B, and C to their final lengths. From here, we notched the end of the tube on Arm A and C using a hole saw and fixturing on the drill press. We deburred these components and prepped them for welding, using the same process previously described. We water-jetted the arm plates for the thrusters out of 0.125” aluminum sheet metal. As with the frame brackets, the water jet manufacturing process required enlarging holes and filing edges of completed pieces. To add the 15° holes for the motor arm, we used a drill press with an angled work surface, which we verified was set at the correct angle with a digital angle finder. Figure 62 shows this drill press setup.

Figure 62. Setup on the drill press to add the angled holes to the motor plates.

After cutting, sizing, and prepping all the components for the motor attachment, we began TIG welding the components together. Because the locations of the motor mount components rely on the motor arm, the welding timeline for each were intermixed. As pieces would heat, we switched focus to other welds to allow pieces to cool for about 45 minutes each. This meant we started out by fillet and butt welding the three aluminum C-channels together and then worked on welding the three arms of the motor arm together. We then welded the arm plates at their specified location on Arm C. Figure 63 shows the completed welds on the motor arm, after thruster installation and attachment to the motor frame.

Figure 63. Welded motor arm, after thruster installation.

From here, we dry assembled the motor mount and motor arm together and marked out the locations for the holders such that the alignment of the two components was compatible —we did this to mitigate any stacked manufacturing tolerance errors. Once we had correctly marked the holder locations, we welded them onto the motor mount. Figure 64 shows the completed motor mount.

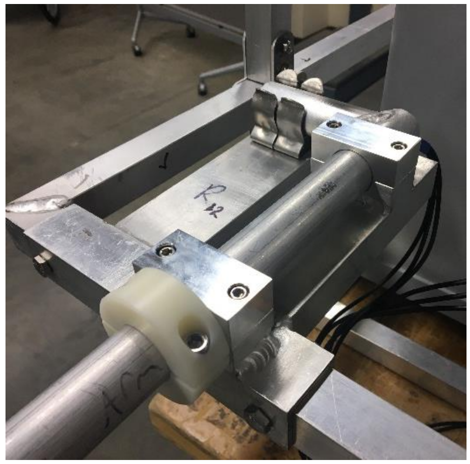


Figure 64. Completed motor mount, with the motor arm through the holders and attached to the frame.

Following the completion of welding, these components were ready for the full system. This in the assembly section.

6.3.3 Payload Box Manufacturing

Since the payload box was a stock product from Hoffman, this section will discuss the modifications made to the payload box as well as the manufacturing of the electronics and electronics mounting.

Two major modifications were necessary for us to use the payload box in our design. The first was to drill holes to mount the Blue Sea Systems power switch provided by Lawrence Livermore, and the second was to drill holes to install the glands that allow cables to pass through the box. Using a hand drill and a 2-⅜ inch diameter hole saw, we drilled a hole in the top right corner of the right side of the box to allow the body of the power switch to pass through the box. Figure 65 shows the process and results of this drilling operation. With the switch in place in the hole, four mounting holes were match drilled into the box using a $^{13}/_{64}$-inch drill bit. For the six cable gland holes, we drilled into the box using a hand drill and a ⅝ drill bit. Two sets of two holes are on the left and right sides of the box for the motor cables to pass through, placed in the center of their respective side panels. The two final gland holes were necessary in the front face of the payload box for the positive and negative battery cables. We chose to place these holes in the corner opposite the switch to allow space for routing the battery cables, since the cables have a relatively large bend radius. If we were to do this manufacturing again, we would recommend using a slightly smaller hole saw and a smaller bit for the cable glands, since there was extra clearance on those holes that is less than optimal.

Figure 65. Drilling of the main power switch hole in the payload box.

The Hoffman box we purchased included studs for bolting electronics mounting plates, and we purchased one of these plates along with the box. To prepare the plate to mount the electronics, we drilled mounting holes for each printed circuit board (PCB) and electrical component. Before drilling, we laid the PCBs and electrical components out on the panel and positioned to allow for adequate cable routing space. Figure 66 shows a partial completion of this layout, with the electrical components from LLNL and the thruster ESCs.

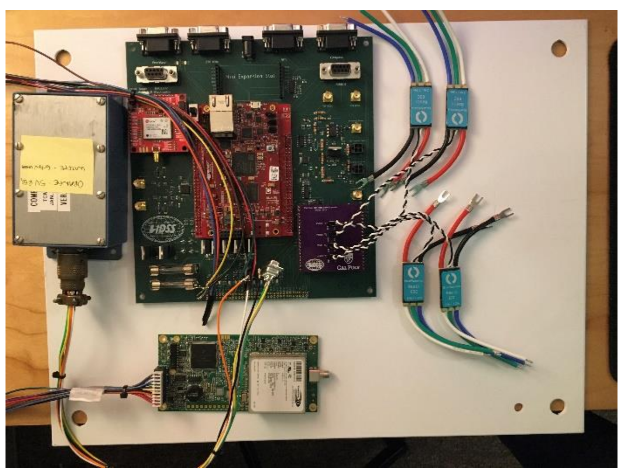


Figure 66. Partial layout of electrical components, to ensure proper spacing.

The main concern when placing the components was ensuring that the cables on the thruster ESCs could reach both the bus bars for power and the core board connections for signal, since the stock cables were very short, especially for power. With the electronics laid out, mounting hole locations for each component were easy for us to mark on the panel with a sharpie. We completed mounting plate manufacturing with a drill press. Table 11 lists the various components that we used, and the drill sizes needed for their respective holes.

Table 11. Drill sizes for the various electrical components.

Component	Hardware Size	Drill Size for Clearance Hole
Core Board	#6-32	#18
FreeWave Radio	#4-40	#30
Bus Bars	#10-32	#2
Fuse Holder	#6-32	#18
Compass	#10-32	#2
Switch	#10-32	#2

Although LLNL provided the PCBs for the core board, compass, and radio, and the cables to connect them, the cables only had connectors on one side. As such the other side had to be soldiered directly into pin holes on the core board. First, we used documentation provided with the cables to determine which signals the connector pins corresponded to. Then, using our wiring diagram in Appendix U: Wiring Diagram, we determined which wires we needed and which core board pin to which we should solder them. We used wire strippers to remove the insulation from the ends of the wires and inserted them into the corresponding hole. Once in place, we used a soldering iron to solder the wire to the core board. Once we soldered all wires to the core board, we could connect the other ends of the wires to the compass and radio, respectively. Figure 67 shows the result of soldering.

Figure 67. Soldered control board, connected to the compass and radio.

The 6AWG cables which connect the prototype battery and carry main power into the payload box were longer than needed, so we cut them to size using wire trimmers. Smaller sections were helpful; we used them to connect the fuse holder, switch, and bus bars, with the longest sections running out of the box and to the battery. To allow for a better electrical connection, we added crimped connector lugs corresponding to the stud size on each component to the ends of these cable sections.

The final manufacturing step for the payload and electronics subsystem involved extending the thruster cables and insulating them. The thruster cables provided with the thruster measured only a few feet, so an extension was necessary to route up from the ends of the motor arms, across the raft, and into the payload box. We originally planned to purchase 8 meters of thruster cable directly from Blue Robotics, since it would come with all three wires in the cable pre bunded and insulated. We would have trimmed two meters each of this cable and soldered it to the ends of the cable provided with the thruster, extending it, and allowing for ample routing length. Unfortunately, the Blue Robotics thruster cable went out of stock before we completed our purchase order, requiring us to find an alternative. To replace it, we ordered 100 feet of 16AGW cable in a spool from Amazon. We cut from this spool in 12 six-foot sections, three for each thruster. After stripping the ends of these wires, we used a soldering iron to connect them to the wires of the exiting thruster cable. Using a heat gun, we applied heat shrink tubing to the soldered joints to insulate them. The heat shrink purchased included adhesive inside which provided a waterproof seal on the joint. At intervals along the wire, we added more heat shrink to bundle the three wires and create a better seal at the point where the wire would pass through the payload box. Figure 68 shows the cable extensions entering the payload box through the cable glands, with tubing to improve the seal.

Figure 68. Thruster cables extensions entering the payload box.

With the payload box components manufactured, the next step was to assemble them.

6.4 Assembly

This section explains the process of assembling each separate subsystems—the frame, motor attachment and payload. In addition, it will outline the final assembly where all these subsystems come together to complete the verification prototype. The subsystem assembly takes place once after manufacturing while the final assembly happens each time LLNL transports the raft between testing locations.

6.4.1 Subsystem Assembly

Assembly of the custom frame involved bolting the three decks together, utilizing the brackets and the vertical riser bars. When tightening all the connections, we used square tool for guidance, to ensure the entire frame subsystem was square. The risers attached to the main deck by sandwiching two cross shaped brackets on the front and back of the frame and 90-degree brackets on the central lift point support. Two T shaped brackets sandwiched on either side of the flash pole mount to secure it to the main deck. Once we mounted all necessary components to the main deck, we attached the lower deck to the lower risers using a single L shaped bracket on all six risers. The upper deck was the final level; it attached to the upper deck risers using two L shaped brackets on each of the connecting corners. Figure 69 provides reference to the fully assembled frame subsystem.

The final assembly for the motor mount includes installing the clips on the clip extension using the correct screws. Similarly, the thrusters connected onto the motor arm using fasteners. Additionally, we added both the end tube cap and the shaft collar clamp onto their specified locations on the motor arm. From here, the arm mounted to the holder using the holders and clips. Figure 69 also shows the completed motor attachment subassemblies attached to the frame.

Figure 69. Completed frame subassembly with the four motor mount subassemblies attached.

Assembly for the payload box assembly included installing cable glands and the power switch to the outside of the box, as well as attaching electrical components to the interior mounting panel and routing cables into the box. We installed the cable glands by hand and, when completed with cable routing, tightened each gland over the cables. If we were to do this again, we would recommend using cable glands with longer shanks. The cable gland mounting shank was too short to pass through the payload box walls, a sealing O-ring, and still allow the mounting nut to thread on. To get around this we removed the O-ring which allowed us to thread and tighten the nut, but it also compromised the seal around the gland. We addressed this use during our testing, discussed further in 7.1.3 Waterproof Testing.

The power switch attached to the box with four 10-32 machine screws and O-rings between the switch and the box to seal the holes. The electrical components bolted to the electronics panel with the corresponding bolt size, shown in Table 11, with spacers on the PCBs to raise them off the panel. With components bolted down, we routed cables and connected them according to the wiring diagram in Appendix U: Wiring Diagram. The antennas for the radio and GPS mounted inside the box using adhesive zip tie mounts and zip ties. Figure 70 shows the completed exterior of the payload box, while Figure 71 shows the completed interior of the payload box.

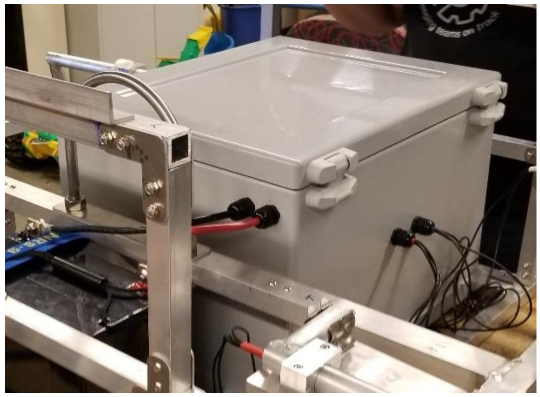


Figure 70. Completed payload box exterior, showing two battery glands and two thruster glands.

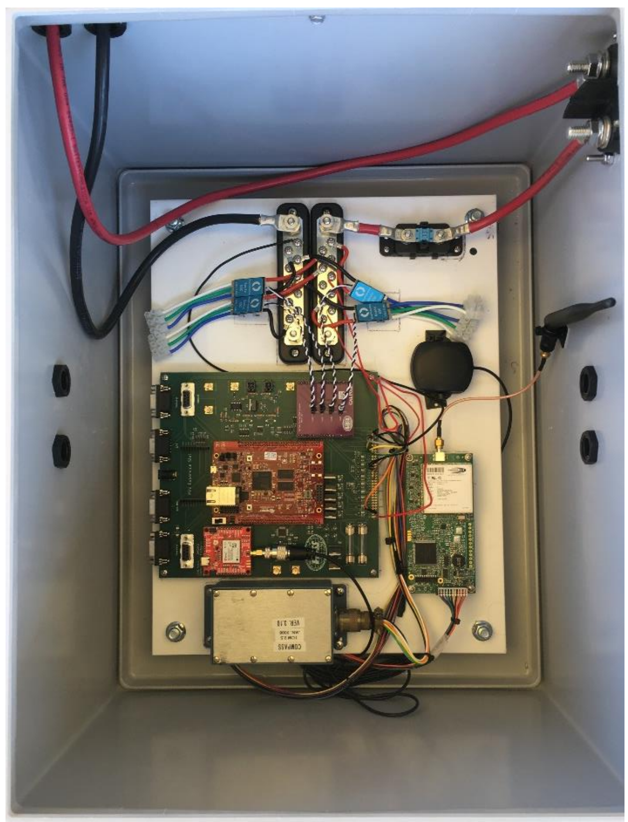


Figure 71. Completed payload box, interior.

6.4.2 Final Assembly

Once we assembled each of the subsystems separately, we moved to assembling the full verification prototype. The first step was to inflate the pontoons to 90% of the recommended pressure. We secured the battery and payload box to the frame using bolts for the box and straps for the battery. Performing this step before attaching the frame to the pontoons allowed for easier access to the underside of the lower deck to ensure a secure connection. With care, we lowered the frame onto the pontoons and attached it with NRS straps running through the D-rings on the pontoons. To secure the frame statically to the pontoons, we ensured the straps were tight, and places such that they prevented pontoon rotation. To ensure that the central lift point rested above the center of mass, we centered the frame on the pontoons. This also helps to ensure proper balance while in the water. After releasing the motor arms from the clips on the motor mount, we connected each of the four motor attachment subassemblies to the main deck with the appropriate bolts. The arms remained in the unclipped position until we released the raft into the water where there would be clearance below the pontoons for the motor arms to rotate to their clipped positions. The penultimate step was to connect all the wiring from the payload box to the battery and thrusters. The final step in completing the assembly was to inflate the pontoons the remaining 10%. By leaving this step until the end, we were able to know that the strap connection was tight locking the frame in place on the pontoons, since the extra inflation puts the straps in greater tension.

6.5 Cost Analysis

Our final project costs for the verification prototype, including all materials purchased and testing fees, are tabulated in Table 12 by purpose. Also provided in Table 12 are the cost estimates made during the design phase for reference. A full breakdown of the final project costs can be found in Appendix V: Final Project Budget, which contains a table of all purchase orders that placed.

Table 12. Final Project Costs by Category

Category	**Estimated Cost**	**Actual Cost**
Preliminary Testing	$130.89	$127.08
Pontoons	$2089.00	$2089.00
Thrusters, ECS and Cable	$906.68	$848.55
Frame Assembly	$454.80	$503.15
Prototype Battery	$200.00	$139.99
NRS Straps	$89.76	$75.77
Motor Mount Assemblies	$300.00	$521.6
Payload Box Electronics	$150.00	$132.85
Payload Box and Hardware	$1,400.00	$1,064.49
Testing	NA	$74.00
Total	**$5,721.13**	**$5,576.48**

Looking at our final project costs, we are not within the prototype budget parameters that we initially established with our sponsors. In later conversations with Mr. Nyholm and Mr. Fuller, they indicated that limited budget overages were acceptable if they would produce a prototype that would function similarly to the final design. The main expense that pushed us over was Hoffman payload box, since we considered less expensive options, but in the end our sponsors agreed that using it would improve the overall quality and usefulness of the prototype as a justification tool. Many of our cost estimates were higher than what we eventually spent because LLNL does not pay tax on purchases, but these savings were cut by higher-than-expected costs in materials for the frame and motor mounts. We also neglected to budget for verification prototype testing costs. Overall, we did a good job of estimating project costs early on, since the total estimated and final costs differ by only $150.00.

Considering only material cost, our final design is well within the final design budget of $15,000, since even with the substitution of the $4,700 Lithionics battery the material and component cost would be around $10,050. This final design cost does not account for manufacturing costs, which will be significant because of the welding time required to manufacture the frame and motor mounts. The cost to LLNL to create a raft from scratch would likely be higher than $15,000 because of the costs of the control and data collection electronics that they provided to us, but these components were outside of the project scope and budget.

7.0 Design Verification

Design verification took place once the prototype was complete to evaluate how the design measured up to the specifications outlined in Table 3. The two categories of testing took place in the form of physical experiments and visual inspection. We designed the raft to meet and exceed each of the specifications but if the raft does not meet the specifications, we will advise recommendations for future modifications to meet the specifications. We have outlined predicted testing plans in previous reports; some slight modifications are necessary due to manufacturing and testing facilities which we explain throughout this section. The design verification chapter focuses on the testing procedures that took place and highlights both analytical and observational results. Table 13 summarizes and identifies which specifications the raft met. Appendix W: Design Verification Report includes the planned verification tests, and the results from those tests.

Table 13. Summary table of specification results.

Spec. #	Specification Description	Target (unit)	Specification meet?
1	Weight without battery	200 lbs.	Yes
2	Average Footprint on Deck	4'x7'	Yes
3	Cost to Manuf. Final Design	$15,000	Yes
4	Shipping Dimensions	6'x6'x6'	Yes
5	Speed	5 ft/s	Yes
6	Payload	10 lb.	Yes
7	Field Assembly Time	5 min.	Yes
8	Battery Life	2 days	Yes*
9	Point of Contact	2 Points	Yes
10	Number of Motors	2 Motors	Yes
11	Waterproof	IP66 adherence	No
12	Stability	Remain upright in 3ft waves	Yes
13	% Purchased Parts	80% OTS Components	Yes

*The specified battery for the final design was not used on the prototype and therefore hand calculation confirm that this specification was met.

The following sections will detail and explain the process for verifying each specification and comment on the results. Following this, we have included a section of recommendations for testing for future use to improve both the testing and design of the raft.

7.1 Verification by Testing

The four main specifications for which we intended to performed tests on the verification prototype were speed (5), payload box impermeability (11), field assembly time (7), and stability (12). Explanations of these tests, including their purpose, plans, and results are in this section.

7.1.1 Speed Testing

The primary goal of the speed test was to verify the top speed of the raft exceeds five feet per second. Functionally, the LLNL rafts should not need to move at this speed for extended periods of time, but should a use case arise, we want to have verified that the raft can move quickly. Appendix X: Test Procedures includes the complete test plan for the speed test of the raft.

To test the raft speed, we transported the raft components to Lake Nacimiento, near Paso Robles, CA. Onsite, we completed final assembly of the raft; this assembly included inflation and attachment of the pontoons, and attachment of the motor arms to the motor attachments. We transported the raft to the water, and using the communication equipment provided by LLNL, we ran the raft along a straight path in the middle of the lake. Unfortunately, our battery did not have enough capacity to complete all test runs that we wanted to complete. However, Mr. Fuller and Mr. Nyholm were able to attend the testing, and brought with them a spare battery, which we swapped onto the raft, and used to complete the last two runs of the test.

The LLNL control board collected various data from the raft movements, including the pitch and roll of the raft, the navigation mode – manual, smart navigation, or auto-navigation and the latitude and longitude position data. The control board logged this data to .txt files, which we imported to Excel as comma-separated values (CSV) files. After parsing the data to consolidate only the positional information, we used the Haversine formula to transform the latitude and longitude data into a distance traveled [26]. Since the control board logged this positional data once every second, this distance traveled also functions as a one-second instantaneous velocity. Figure 72, Figure 73, Figure 74, and Figure 75 show the final data from each of our four tests, respectively. The raw data, transformed data, and example calculations are in Appendix Y: Speed Test Data.

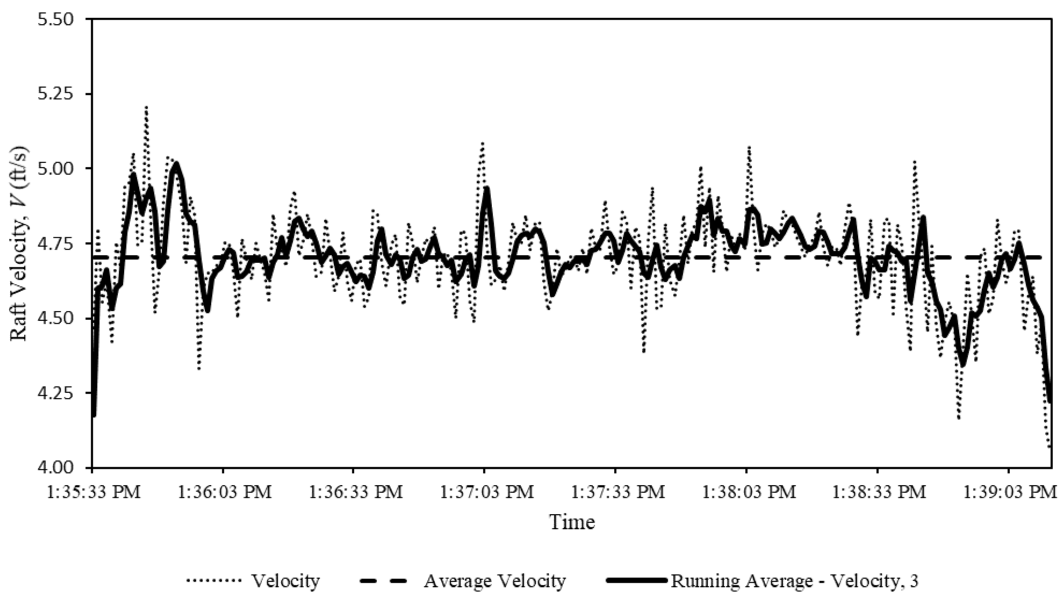


Figure 72. Velocity data from Test 1 on the lake, before battery swap.

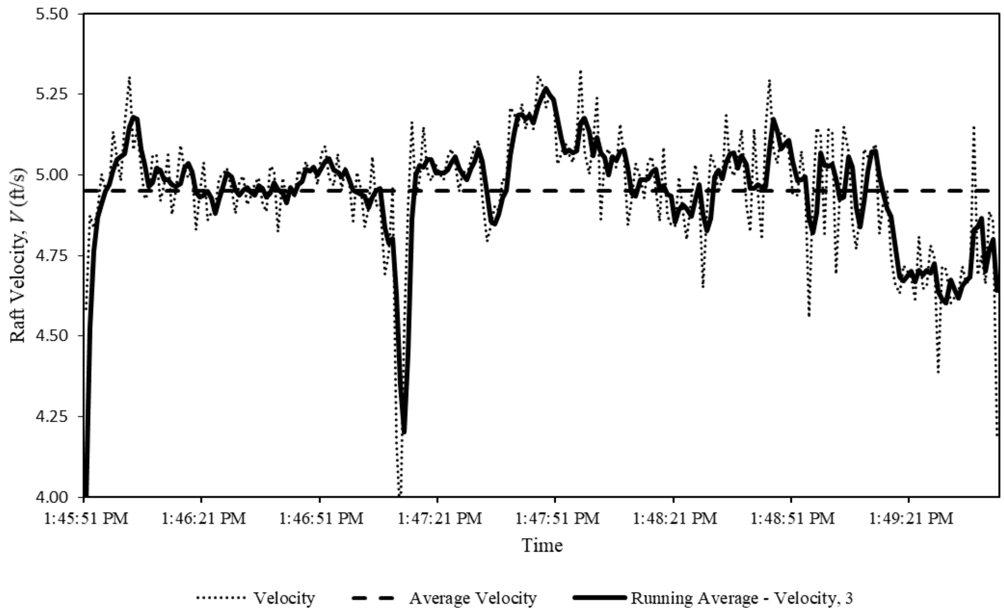


Figure 73. Velocity data from Test 2 on the lake, before battery swap.

The battery we purchased to use for our verification prototype testing is smaller than the one that we have specified for the final design, as previously explained, and justified. As such, the capacity was such that we could only complete the first two tests on this battery. We swapped the battery with the one that our sponsors had intentionally brought with them and continued with tests 3 and 4. Because we wanted to ensure that the battery would last long enough for us to drive the raft to shore, we shortened the test length of these tests to the originally designed 500 feet, instead of the 1000 feet over which we ran the first two tests.

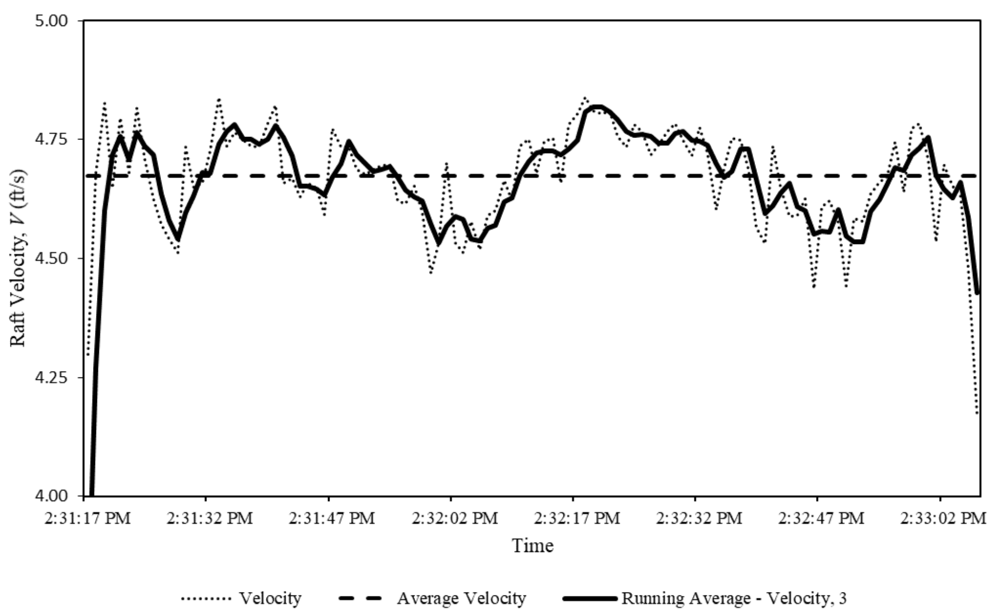


Figure 74. Velocity data from Test 3 on the lake, after the battery swap.

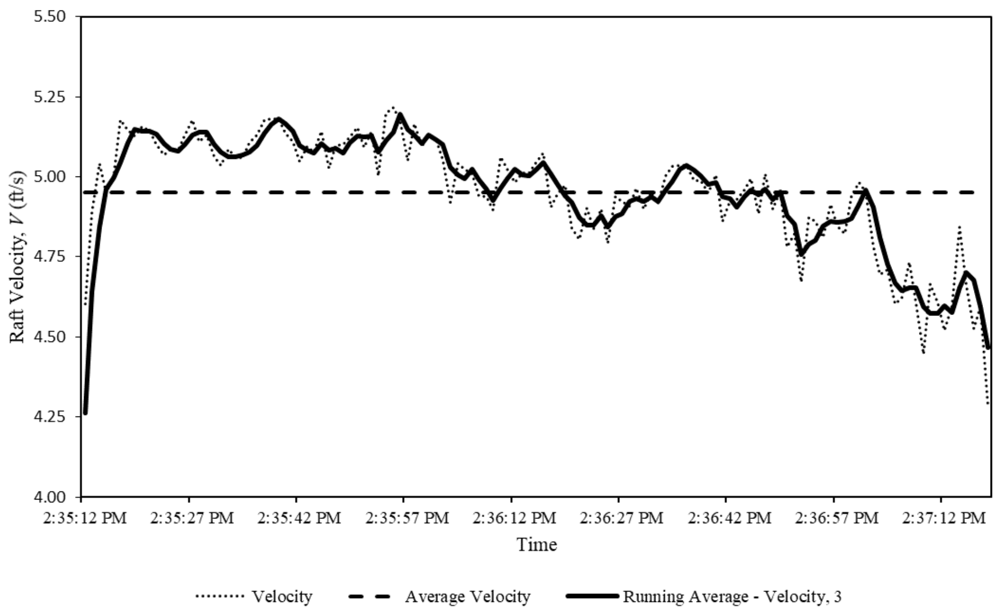


Figure 75. Velocity data from Test 4 on the lake, after the battery swap.

The analyzed data is promising. However, this data does come with caveats. The raft weight and configuration used during testing were similar, but not identical, to the final design. Figure 76 shows the raft after we had finished testing. The motor arms are in the upright position to make it easier to access the handles on the pontoons. This is a position that the motor arms would never be in during normal operation; we firmly recommend that the end user never rotate the arms to this position, except for single raft transport with no potential for stacking.

Figure 76. Completed raft after testing at Lake Nacimiento.

As seen in Figure 76, we did not add the light pole, or the flash head to the raft during testing. We received the flash pole that we intended to use, but manufacturing mistakes prevented adequate installation in the flash pole tube, and we felt our replacement tube was unstable enough to potentially compromise the testing data. Additionally, the payload box and battery were not at their final design weight. Each of these design considerations will impact the speed that the raft can achieve.

Furthermore, the operating conditions will also have an impact on the speed of the raft. We made a conscious choice to test at a lake, as we wanted the first voyage of the verification prototype to occur in a controlled environment. In addition to the little to no wake on the lake surface, we suspect that the controlled environment also reduced the underwater currents that would act on the raft during operation in the ocean. Finally, the weather conditions during our test were optimal, and the lack of strong winds may have been a factor in the observed raft speeds. When these operation conditions are sub-optimal, there may be a large effect on raft speed, which is yet unknown.

There were potential sources of error for these test runs as well. The LLNL control system needs accurate calibration before its installed and used in the water, and our unfamiliarity with the system prevented us from performing this calibration beforehand. While Mr. Nyholm and Mr. Fuller were able to guide us through a calibration before the first set of testing, we had neither the equipment nor the appropriate controls to verify the calibration. Another potential source of error also comes from the control system. LLNL tuned the control system to the thrust output and weight of the current rafts, so that the adjustments from the control system help the raft settle to a desired heading or position. Since this system is a part of the control board operating system, we had no options to adjust the system. This meant that during testing, we saw wild overcompensation and overshoots. The raft would perform figure eights as it moved beyond a coordinate set and tried to turn around and settle again. On its own, this may not be a problem, but when coupled with the frequency of coordinate logging, there may have been some unintentional aliasing of the position data. Additionally, the positional calculations assume a straight-line path between coordinates, and while this may be an appropriate approximation during the middle of the test, it may not hold at the beginning or end, when the raft is preparing to move towards a target or homing in on a final location, respectively.

As this test is the only one for which we gathered and processed numerical data, we performed an uncertainty analysis as well. The data we gathered included latitude and longitude data, with a precision of $1.0 * 10^{-7}$ degrees. Since we were not able to calibrate the GPS and we did not collect baseline data, this precision is the best start for an uncertainty analysis.

Because of the complicated nature of the Haversine formula and calculations therein, we chose to use the method of general uncertainty propagation to find an uncertainty value for the final distance traveled. As shown in Appendix Z: Uncertainty Calculations, this involves taking the partial derivative of the base formula with respect to each of the independent variables and multiplying each by the uncertainty for the respective variable. Taking the root-sum-square of each of these values should provide a total uncertainty for the overall formula. For the two valid data points presented in Appendix Z: Uncertainty Calculations, this total uncertainty is ± .05 feet per second.

While theoretically we should repeat this for every set of two consecutive positions, this would require more than 600 separate calculations for the data presented in this report. This is easily done in Excel, but the benefit from these calculations is likely to be minute. The positional data shows a relatively small range, and so the uncertainty calculations are unlikely to show a larger uncertainty. Even for all Run 1 and Run 2 data, the largest uncertainty is ± .05 feet per second, and only for a minority of the data within this data. As such, assuming an uncertainty of ±.05 feet per second for all the valid data is a conservative, and appropriate, assumption. Even with this uncertainty in the speed data, the raft still reached speeds above the target five feet per second.

As an aggregate, the testing data confirms that the raft can reach instantaneous velocities over five feet per second. There are sections of data in each of the tests that indicate that we may have reached sustained velocities over five feet per second for a small timespan, but it seems that the raft may not be able to sustain these speeds for extended periods of time. Regardless, this data is sufficient to return an achieved specification.

7.1.2 Field Assembly Time Testing

The intent of the field assembly test was to record the average time it would take to assemble the raft such that it would be ready to deploy into the water. For our design, this meant installing the light pole and clipping in the motor arms for travel mode. The specification our design needed to meet was an assembly time of less than 5 minutes. The outline for the test included recording then summing the time it took to install the light pole and clip in the motor arms. We conducted a total of five runs for each portion of the field assembly to find the average time. According to the test results, the average time for field assembly is 45 seconds. Table 14 shows the raw data taken from the test.

Table 14. Field assembly test results, for each component separately and in total.

Run	**Light Pole Time [min:sec]**	**Motor Time [min:sec]**	**Total Time [min:sec]**
1	0:42	0:15	0:57
2	0:29	0:16	0:45
3	0:31	0:15	0:46
4	0:23	0:14	0:37
5	0:29	0:13	0:42
		Average Total Time	0:45

Looking at the test results, we are far below the required criteria of a field assembly time of no more than 5 minutes. While the results from the test show a very low field assembly time, we acknowledge that we conducted this test in an ideal and controlled environment and is not representative of the conditions out in the field. We anticipate that the field assembly time will be larger when considering rough sea conditions and the unstable movement from lifting with the crane. However, even in these conditions, we believe that the field assembly time will still be below the required specification.

7.1.3 Waterproof Testing

To route wires in and out of the payload box, we added connector glands to the walls of the payload box. Unfortunately, doing so improperly could compromise the watertight nature of a Hoffman box. To ensure none of the electrical components in the payload box would get damaged by water, we conducted a waterproof test. This test included pouring and splashing water onto the payload box to check for any areas of leakage. Water was specifically aimed at places where glands had been installed. Figure 77 shows one of our team members conducting the waterproof test.

Figure 77. Andrew Fleming conducting a waterproof test on the payload box.

We placed dry paper towels inside the payload box to detect any sign of water in the box. The results from the test showed that some of the glands were not watertight and allowed water to seep into the box. To remedy this, we purchased a marine grade adhesive silicone sealant and applied it to all six glands. Since these were the only areas of concern, we felt confident that the sealant would completely waterproof the payload box. While this is sufficient for our testing purposes, more stringent testing should be performed to ensure that the payload box still meets IP66 standards with the box modifications.

7.1.4 Stability

The testing plan for stability is in Appendix X: Test Procedures but due to complications with testing resources we were unable to conduct this test. While we did not conduct a formal test, during the speed test, the raft incurred waves from passing power boats. The waves were approximately two to three feet in height at a much higher frequency than for our intended test plan. By visual inspection we feel comfortable with the stability of the raft. We do recommend that further stability tests take place but for the initial prototype, we are impressed with the performance.

7.2 Verification by Inspection

We analyzed the remaining specifications in Table 3 through both visual and analytical inspection, as specified and appropriate. We confirmed specifications regarding variables such as weight, average footprint on deck, and shipping dimensions visually, with basic tools like tape measures and scale. We verified cost analysis, component quantity, and percent of purchased parts by examining our bill of materials in Appendix L: Indented Bill of Materials. Finally, we verified any remaining specifications using our best engineering judgment.

7.2.1 Weight Inspection

During the design phase of the project, we calculated or found weight predictions for components and subassemblies using SolidWorks materials and manufacturer data. To check these predictions and ensure that the raft met weight specifications, we weighed completed subassemblies using a scale. We used a 1000-pound digital scale from our senior project room to weight subassemblies in batches. The scale had a resolution of 0.2 pound. For long or bulky components that we could not easily place on the scale by themselves, we had a team member weight themselves alone and then weight themselves holding the component. This way we could subtract the person's weight and get the component weight. Table 15 shows a breakdown of weighed components.

Table 15. Measured component weights.

Subassembly	Component	Measured Weight (lb.)
Pontoon	1x Pontoon	13.8
	Straps	1.8
Frame	Frame	26.4
Motor Mount	1x Mount	1.3
	1x Arm	2.8
Payload Box	Payload Box	30.8
Light Pole	Fiberglass Pole	2.6

To make sure that the weight of the pontoons does not vary with their inflation state, we weighed the pontoons with and without air; we found that there was no significant weight difference between the two configurations. For the frame, we weighed it with all brackets and fasteners installed, including the flash pole pins. The motor mount weight included fasteners used to attack the motor arms and to mount to the frame. The motor arm weight included the weight of the thrusters and the thruster electrical cables. The payload box weight included the weight of the fiberglass box as well as all the internal mounting panel, electrical components, cables, and fasteners that allow the raft to function. The light pole weight only included the pole itself since we did not have access to the flash head itself. Table 16 shows a comparison between measured and predicted subassembly weights.

Table 16. Complete raft weight, by subsystem.

Subassembly	**Predicted Weight (lb.)**	**Measured Weight (lb.)**
Pontoons	40	30.8
Frame	23	26.4
Motor Mounts	13	16.4
Payload Box	30	30.8
Light Pole	18	17.6
Total	**124**	**122**
Total w/ Battery	191	189

Although components like the pontoons ended up weighing much less than predicted, the overall weight ended up being close to the predicted weight because of weight increases on the frame and motor mounts. The difference in weight of the frame is mostly due to the brackets and fasteners used on the prototype, so we expect a fully welded frame to be closer to the original prediction. We have greatly surpassed our weight without battery goal, coming out 78 pounds lighter than our 200-pound limit. Our raft is light enough that even with a 67-pound battery, we are 11 pounds below the limit. This means that four people can lift and move the raft by hand, since they will each be carrying less than 50 pounds.

7.2.2 Footprint on Deck Inspection

To check whether our raft met our footprint on deck goal we fully assembled the raft and then used a tape measure to measure the full length and width of the raft. Maximum raft dimensions are below in Table 17. For the length, we measured from the forward tip of each pontoon to the aft tip. The two measurements were slightly different due to small manufacturing differences, so they we averaged both to get the length listed. We defined the width as the distance between the outside edges of the thruster housings on either side of the raft. We used this measurement since it is the widest distance and therefore most conservative. The raft width between the outside edges of the pontoons is just a few inches shorter.

Table 17. Raft footprint measurements.

Dimension	**Measurement (in.)**	**Measurement (ft)**
Length	109.7	9.1
Width	66.4	5.5

The raft ended up being longer than planned because our pontoons are custom made. We specified eight feet for our order, but Maravia made the first batch at nine feet and there was not enough time to have a second batch made closer to specifications. Although this put us farther out of spec. with our footprint on deck requirement, we also note that the design allows stacking. Even with these maximum dimensions, the average space on deck is within specification. Additionally, the pontoons can deflate to save space if necessary.

7.2.3 Cost to Manufacture Final Design Inspection

Our final cost to manufacture our design was $5,500 which did not include the desired battery for the final design. We slightly exceeded our project budget, but the budget for the final design was set much higher, at $15,000. In total, our materials cost for the final design reach just under $10,000, leaving the rest for manufacturing. Conservative estimates for manufacture of the frame and motor attachments, and for final frame assembly keep the total build cost under the total budget. However, since we have little details about the manufacturing capabilities or workflow, we cannot provide an accurate final cost estimate at this time. Based on our estimations, we have met this specification, but this may shift as the project evolves beyond the scope of this report.

7.2.4 Shipping Dimensions Inspection

We verified the shipping specification when we shipped our prototype to LLNL. Based on frame dimensions and rough measurements for packaging all the components of the raft, we anticipated that the raft would meet the shipping criteria. After shipping the raft to LLNL, we were able to confirm that the entire raft can be packaged and shipped on a standard pallet, and thus meets our shipping dimensions.

7.2.5 Payload Inspection

The minimum load that the raft must hold in the payload box is ten pounds. Knowing this, we designed the frame such that it would be capable of carrying such loads. Initial analysis included doing FEA analysis on the frame structure such that it will not fail under the load of a stacked raft. Through this FEA, our design proved to withstand the load of a stacked raft and therefore knew it would be able to hold a mere ten pounds. To further verify this, we observed that our prototype was able to hold our 30-pound payload box during the duration of our speed test. This tells us that we met and exceeded the minimum payload specification of ten pounds.

7.2.6 Point of Contact Inspection

For our design, we specified less than two contact points for lifting the raft. As a result, we intentionally designed for one lift point aligned above the center of mass. Doing so ensures stability of the raft during lifting. Having one point of contact not only meets the criteria, but also reduces the hassle of connecting onto multiple lift points.

7.2.7 Number of Motors Inspection

The minimum number of motors our design could have was a total of two motors. With the thrusters that we chose, we calculated that four motors would be sufficient to move the raft at our desired speed and therefore moved forward with implementing them into the final design. A simple inspection shows that we meet the minimum number of motors desired.

7.2.8 Purchased Parts Inspection

The goal for purchased parts was design a raft that consisted of 80% of the shelf parts. Regarding the raft build that we constructed, the fame and motor mount assembly contained extensive stock metal parts welded together. For the final design, we have specified that the frame and motor mount assembly are custom fabricated, and the remainder of the raft components are off the self with minimal to no modification. When we consider the frame and aluminum motor mounts as one part, the raft meets the specification of consisting of 80% off-the-shelf components.

7.3 Recommendations for Future Testing

With the limited time available for testing, we strongly recommend future testing. The main areas are stability, speed, battery life, and strength. As stated previously, we were unable to formally conduct a stability test so qualitative test data should be acquired by using the test procedure in Appendix X: Test Procedures before active missions. Additionally, the speed test that took place was in an ideal testing environment and we advise further evaluation in more accurate use conditions before deployment on missions. The battery used in the initial testing was not the final design specified battery. The cost of the specified battery was higher than our budget and our preliminary calculations concluded that it achieves the desired performance. We recommend that future iterations use the final design battery, and that LLNL analyze longevity prior to deployment. Finally, the frame uses a combination of welding and brackets for strength and stiffness. The final design specifies a fully welded frame, and the team recommends an evaluation of frame strength before the deployment of valuable electronics onto the open ocean. While we would have liked to continue these tests, we are confident that the design presented will be valuable for the next design iteration that can complete these recommended future tests.

To assist in the execution of future tests and to help transition the current operating procedures to accommodate the new raft design, we have drafted a user manual. This manual should be read and understood before attempting to assemble the raft and deploy it on missions. The manual in Appendix AA: User Manual includes instructions for assembly from the subassembly to the full assembly level, instructions for the proper deployment of the craft, and instructions for the proper temporary storage. It also includes instructions for maintenance and repair of the raft and its components.

8.0 Project Management

This section describes the project management process followed throughout the project. It outlines the major project milestones and deliverables for the entire project. Also, in this section is a Gantt chart that shows more specific tasks we have complete, in the lead up to the major milestones.

This project followed the engineering design process. The first steps were to establish the problem and research the background to it; this document should reflect those efforts. After the problem definition phase, we continued with design ideation. During this phase, we constructed conceptual prototypes and undertook preliminary analysis. All this ideation culminated in an initial design direction. From there, we began design analysis, ensuring that the proposed design functions as intended and meets the customer needs and wants. We built a structural prototype and created a detailed CAD model and appropriate drawings to communicate our design. After the sponsor approved the finalized design, we began construction of a verification prototype. Following construction, we tested the prototype to ensure that it meets the engineering specifications already described. The final step in the process was to participate in a virtual project expo, where we presented our work to peers, faculty, and sponsors.

8.1 Major Milestones Achieved

To ensure that we have completed a comprehensive design process in a timely manner, we have set major milestones to accomplish by specific dates. Table 18 outlines the major project milestones, with short descriptions, for the entire project.

Table 18. Major Project Milestones.

Deliverable	Description	Date
Scope of Work	An initial document that establishes the project background, design objectives, and project timeline	October 13th, 2020
Preliminary Design Review (PDR)	A preliminary report of the design direction and solution, detailing the intended solution to the problem	November 12th, 2020
Interim Design Review	A peer-reviewed presentation, to present the major design decisions and get feedback on potential issues	January 14th, 2021
Critical Design Review (CDR)	A pre-production report, with all information necessary to build and verify the final design	February 25th, 2021
Verification Prototype (VP)	A complete and functional prototype of the final design, ready for testing and delivery	May 14th, 2021
Senior Project Expo	An exhibition of the tested design, outlining the entire design process and the results	June 3rd, 2021
Final Design Report (FDR)	A final report of the entire design process, including results of the process and suggestions for future work	June 8th, 2021

8.2 Gantt Chart Effectiveness

Table 18 shows the major milestones for the project, but it does not provide enough resolution on the project to be a complete planning tool. We have created a Gantt chart that shows a higher resolution of the project. Appendix BB shows the current version of the Gantt chart, updated to highlight tasks from the start of the project through the completion of the project.

In general, a Gantt chart is an extremely effective tool for large projects involving multiple moving components. Throughout the progression of our design, the effectiveness of the Gantt chart as a tool for our team was restricted by two key factors. The initial conflict arose with the inability of the entire team to access the document due to software limitations. If the document were easier to access and edit on a shared drive our team could potentially have utilized the tool more effectively. Instead, only one member of the team could access it and the software was slow. The second challenge that severely limited our team's ability to utilize the Gantt chart was due to the extremely dynamic progress throughout the purchasing, manufacturing, and assembly stages of the project. Due to the current COVID 19 environment, shipping and manufacturing times were extremely difficult to predict which led to the Gantt chart becoming a nuisance. While the Gantt chart was effective as a planning tool in the first half of the project when deadlines were rigidly structured, we transitioned away from it for the remainder of the project.

8.3 Changes for Future Projects

Throughout much of the project our team structure and management proved to be effective. Some of the team management elements that led to our success were effective communication, weekly status reports, and guidance provided biweekly on canvas. While working virtually throughout this year has been difficult, the ability to meet on zoom proved to be a very beneficial asset. The platform provided a quick and convenient medium to conduct meetings that worked for our four varying dynamic schedules.

While our team had great success in project management, we did learn about some changes to implement in future projects. As discussed in the previous section we did not fully utilize the Gantt chart. The time it took to update the file could have been used more effectively for a group update meeting or other tasks to further the design. While having a structured outline for large projects is crucial, depending on the project, a software or method should be selected that best fits the people and goal involved. An additional observation we made that could benefit future projects would be to designate a project lead after selecting a design direction. We think it best to avoid this designation in the early stages to eliminate possible influence during brainstorming and ideation, but after identifying a design direction, considerable time and effort is put into component selection and purchasing. During this time, a team lead can oversee the various moving parts and details to ensure progress does not fall behind. We did not have an assigned team lead, so while our team was able to keep on top of deadlines well, more structure would have made the process go smoother. Throughout this project our management structure in combination with attention to detail provided a basis to grow as engineers and team members.

9.0 Conclusions and Recommendations

As a team, we went through all the key aspects of the engineering design process starting from problem definition and ending at full system design testing. Our team is satisfied with the work we produced and credit the performance and functionality of our design to our attention to detail in each phase of the engineering design process—the following section will highlight our notable team achievements. While our team is pleased with these overall achievements of this project, we also recognize the limitations that we have encountered along the way. Though we will no longer be working on the raft, our team has discussed and considered these limitations and will acknowledge this in a later section.

9.1 Project Achievements

In earlier sections, we discuss how our design meets almost all the baseline specification placed by our sponsor—in fact, our design meets multiple desired specifications as well. While we are proud of these achievements, this is mostly a product of our teams' attention to detail and organization. We believe that this contributed to the overall success of the project from the start to the end. When the project was originally presented to us, each member was set on producing a project that would leave some lasting impact with LLNL. Our team was firmly set on this such that both the sponsors and our team agreed to broaden the scope of work to encompass the root problem with their current fleet of rafts and discuss what improvements LLNL was looking for in a new design. By voluntarily establishing a high expectation for this project early on, we were able to keep the momentum throughout every step of the project.

This proved to be useful in many parts of the design process. During ideation, we generated and iterated through many designs, carefully considering the strengths and weaknesses of each proposed design. Throughout the duration of detail design, our team was careful to design for functionality as well as manufacturing—which helped alleviate the manufacturing portion of the project. Our team understood the complications we would run into with manufacturing and accounted for five times the number of hours it would take to completely build to project.

Similarly, many of our team members were experienced in ordering components from vendors and mindful of these lead times and ensured that we placed orders in a timely manner. This helped meet our established manufacturing timeline and help achieve the completion of the prototype for successful prototype testing.

9.2 Project Limitations

Though we are pleased with much of our project, we acknowledge the limitations that our team was unable to overcome or account for. The compact timeline of the project means there were certain parts of the engineering process that we were unable to fully engage or explore more in. We found this to be especially true in the research, design and manufacturing phases of the design process. Due to the accelerated timeline, our team was unable to spend time fully researching information regarding patents and standards and recognize that we may not have fully adhered to these aspects of the design process. In addition to this, we accept our level of experience as engineering students and understand that there are likely design elements that may not be common practice. Furthermore, our teams' skills in manufacturing and the lack of manufacturing resources surely limited our ability to produce a high-quality prototype.

9.3 Second Iteration

While the project was successful by all accounts, we would do the project differently were we to start it over again.

One of the first things we would do differently is that we would give ourselves much more time for the project overall. While the constraints of Senior Design are necessary to ensure that design project complete before people graduate, the time constraints may have limited the quality of work that we were able to produce. More time to ideate may have produced different designs, and more time to complete more refined analysis may have produced better justification for the chosen design. The scope of our project limited the time that we could spend on these portions of the design.

Additionally, we were unable to complete more than one cycle of the engineering design cycle. While this was necessary for our timeline, if we were to do it again, we would want to create multiple full-system prototypes, to better refine and improve on the design. This would help us to find the issues with the design, and then correct them. Similarly, it would have been nice to see a fully welded frame; we made the correct choice to simplify the design for a verification prototype. In a second attempt at the project, we would prototype the final design, to better understands its strengths and weaknesses.

9.4 Next Steps

With the completion of this Senior Design project, the future of the prototype and design now rest on our sponsors at LLNL. We recommend these next steps, in no order, to continue to improve and refine the design.

- We recommend further FEA analysis, to ensure the designed frame will withstand both the loading cases we did consider and those that we did not consider.
- We recommend continued testing with the verification prototype to verify its stability on water.
- We suggest that this raft frame not be used in the open ocean before further testing. Additionally, LLNL should remanufacture the frame using a fully welded frame instead of bracket replacements. Lifting and stacking testing should be completed with this new frame.
- We recommend that LLNL reconsider the layout and arrangement of components in the payload box to allow for the inclusion of additional data collection equipment.
- If possible, we think that the purchase of one Lithionics battery for testing purposes would make testing results more useful.
- We recommend working with Maravia to refine the pontoon design, specifically to ensure the D-rings properly restrain the pontoons from moving relative to the frame. Additionally, attempts to reduce the length of the pontoons could be made to reduce raft footprint size further to the originally designed 8ft, but the marginal benefit must be weighed against increased manufacturing difficulty.
- LLNL should also consider moving the light pole mount to the other side of the frame to prevent it from interfering with the crane when lifting the raft. This will significantly change raft CG location and should be accompanied by lifting testing, but it will likely improve the lifting process. Additional support for the light pole and mount should also be considered.

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Appendices

A. Appendix A: Quality Function Deployment: House of Quality

Correlations	
Positive	+
Negative	−
No Correlation	

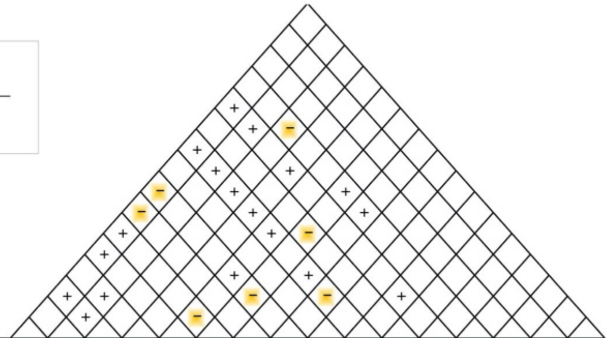
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: LLNL Research Raft

Revision Date: 11/5/2020

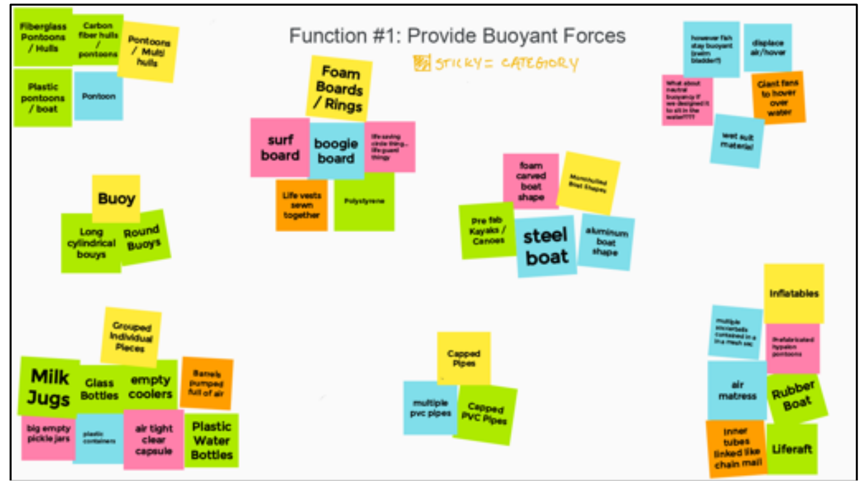


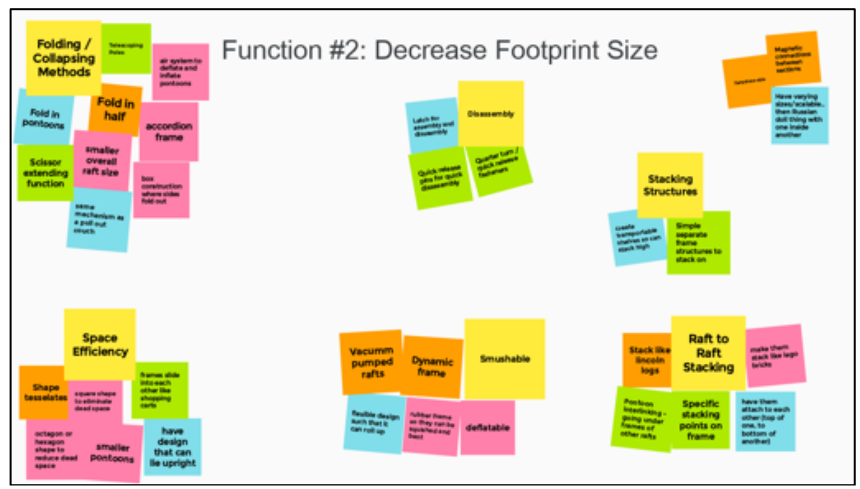
Row #	WHO: Customers: Relative Weight	Paul Nyholm	Manufacturers	LLNL Crew / Operators	Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) \ HOW: Engineering Specifications (Tests)	Weight	Footprint on deck	Cost to Manufacture	Shipping Dimensions	Speed	Payload	Field Assembly Time	Battery Life	Point of Contact	Number of Motors	Waterproof	Stability	% Purchased Parts				NOW: Curr. Products: Current Research Raft	Liquid Robotics Wave Glider	FDOT Bridge Inspector Craft	Pills Research Raft	Seafloor Echoboat 240	Row #
						Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16						
						Direction of Improvement	▼	▼	▼	▼	▲	▲	▼	▲	◇	◇	◇	◇	▲									
1	12%	10	9	10	9	Lightweight	●	○	○	○	●	●	▽			○		○					0	5	1	4	2	1
2	10%	8	7	9	9	Easily Shippable	●	○	▽	●			○			○							0	4	0	4	2	2
3	7%	10	3	4	9	Carries Payload						●		○		▽		●					5	2	4	1	4	3
4	3%	6	1	2	9	Drone Landing Capability		○		○		●						▽					0	1	0	0	0	4
5	6%	9	1	6	9	Stable in water	○	○				▽				●		●					5	4	3	4	4	5
6	8%	9	6	4	9	Waterproof Electronics Box		▽				▽					●						5	5	5	5	4	6
7	9%	5	7	9	9	Short Shipping Assembly Time	▽				▽		●										1	3	1	3	4	7
8	7%	4	10	1	9	Uses Standard Materials			●			●	▽						●				5	1	4	2	2	8
9	9%	4	9	9	9	Uses Standard Fasteners			●	▽			○						●				5	2	4	2	2	9
10	6%	6	1	10	9	Short Field Assembly Time		○		▽			●										4	4	3	4	4	10
11	7%	5	4	9	9	Stackable	●	●					▽			▽							0	0	0	0	0	11
12	5%	8	2	2	9	Differential Motor Steering					○			▽		●							0	0	5	0	0	12
13	5%	6	1	8	9	Long Mission Time								●									3	5	5	3	4	13
14	6%	6	1	10	9	Easily Launched/Retrieved	○	▽							●								2	4	2	3	2	14
15	0%																											15
16	0%																											16

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HOW MUCH: Target Values	200 lb	4'x7'	$15,000	6ft x 6ft x 6ft	5 ft/s	10 lb	< 5 minutes	2 days	2 points	2 motors	yes	Remain upright in 3ft waves	80% OTS Component			
Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9			
Technical Importance Rating	303.8	189.1	194.6	149.3	129.5	273.5	218.2	73.52	55.85	172.1	70.06	150	149.2	0	0	0
Relative Weight	14%	9%	9%	7%	6%	13%	10%	3%	3%	8%	3%	7%	7%	0%	0%	0%
Curr. Products: Current Research Raft	0	2	1	0	5	5	3	5	0	5	5	5	3			
Liquid Robotics Wave Glider	5	4	2	3	0	3	2	5	0	0	5	5	2			
FDOT Bridge Inspector Craft	3	2	1	2	5	3	2	1	0	5	5	3	3			
Pills Research Raft	5	4	2	5	2	3	3	3	4	5	5	3	3			
Seafloor Echoboat 240	5	2	5	1	5	5	4	0	0	0	5	4	3			
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

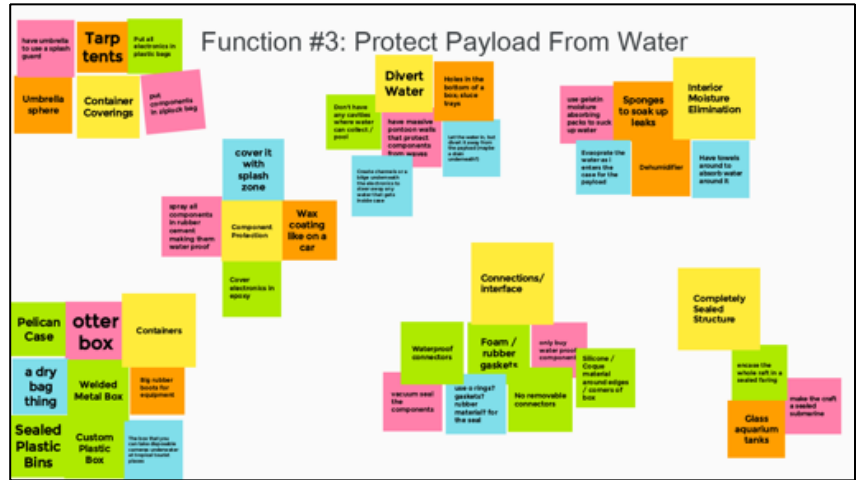
B. Appendix B: Brainstorming Session Results

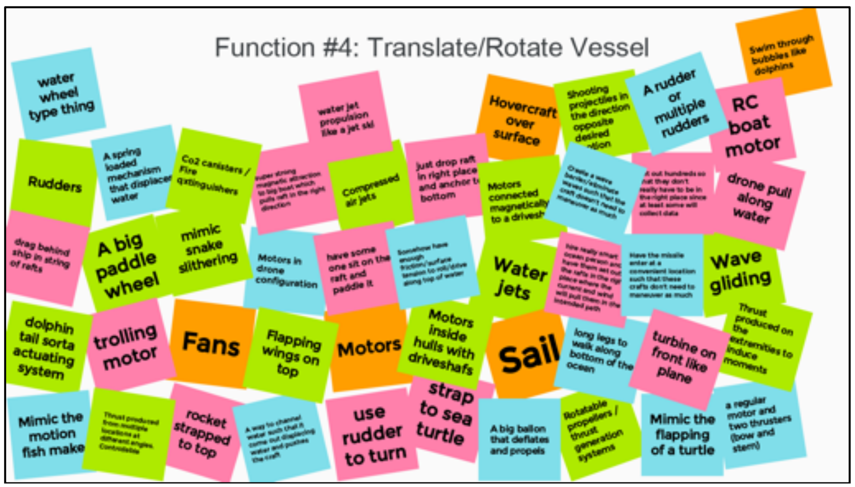
This appendix includes the results from all of the brainstorming sessions. Much of the ideation we undertook utilized this method. Each set of images shows the brainstorming on one function. The first image in each set is the initial collection of ideas; the second image shows the refined ideas, which we sorted into appropriate categories.

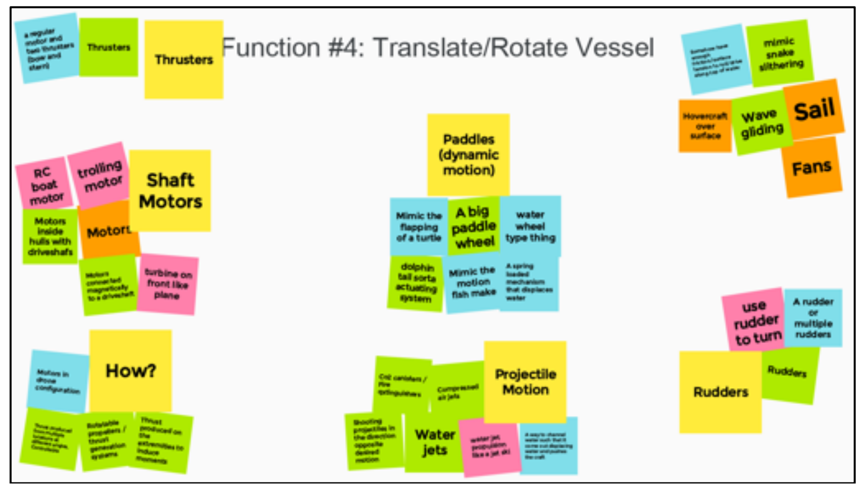


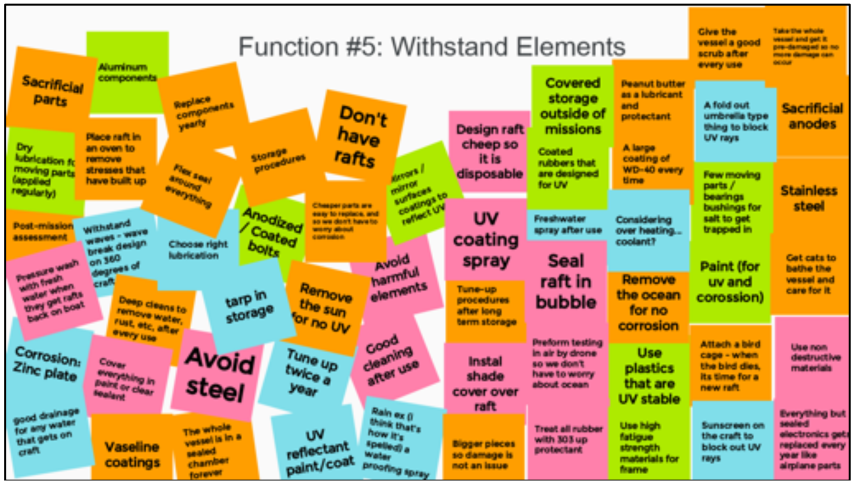


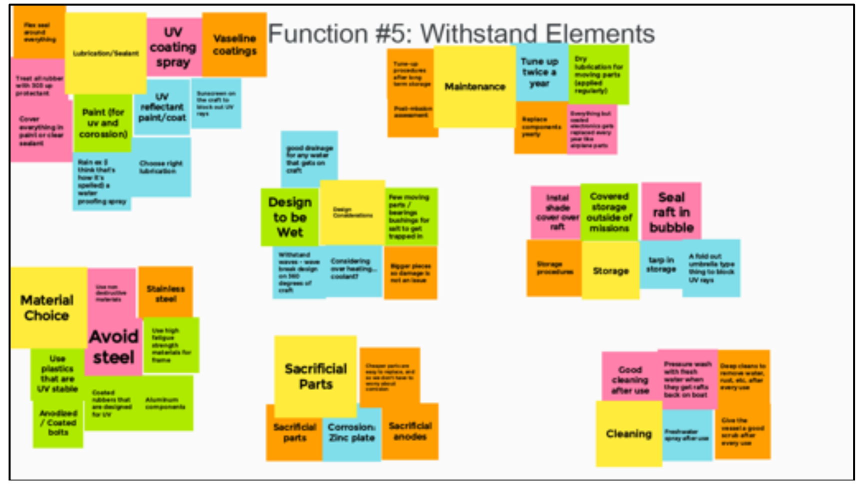

Function #3: Protect Payload From Water
otter box
Ziploc bags
Custom Plastic Box
Sponges to soak up leaks
Don't put the payload in the water
Pelican Case
Get rid of the water in the ocean
Wax coating like on a car
Use fans to blow mist away
Umbrella sphere
Dehumidifier
cover it with splash zone
Welded Metal Box
a dry bag thing
Tarp tents
Foam / rubber gaskets
Sealed Plastic Bins
Glass aquarium tanks
Bread
Add rice to absorb water


Function #3: Protect Payload From Water
Tarp tents
Divert Water
Umbrella sphere
Container Coverings
Interior Moisture Elimination
cover it with splash zone
Connections/ Interface
Completely Sealed Structure
Pelican Case
otter box
Containers
a dry bag thing
Welded Metal Box
Foam / rubber gaskets
Sealed Plastic Bins
Custom Plastic Box
Glass aquarium tanks

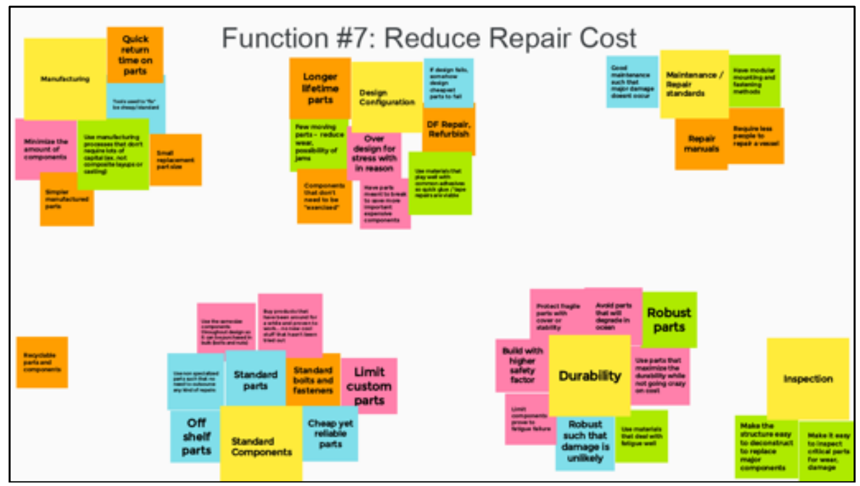

Function #4: Translate/Rotate Vessel
water wheel type thing
Hovercraft over surface
A rudder or multiple rudders
RC boat motor
Rudders
drone pull along water
A big paddle wheel
mimic snake slithering
Water Jets
Wave gliding
dolphin tail sorta actuating system
trolling motor
Fans
Flapping wings on top
Motors
Sail
turbine on front like plane
Mimic the motion fish make
rocket strapped to top
use rudder to turn
strap to sea turtle
Mimic the flapping of a turtle


Function #4: Translate/Rotate Vessel
Thrusters
Sail
Paddles (dynamic motion)
RC boat motor
trolling motor
Shaft Motors
Wave gliding
Fans
A big paddle wheel
water wheel type thing
How?
Projectile Motion
Rudders
Water jets

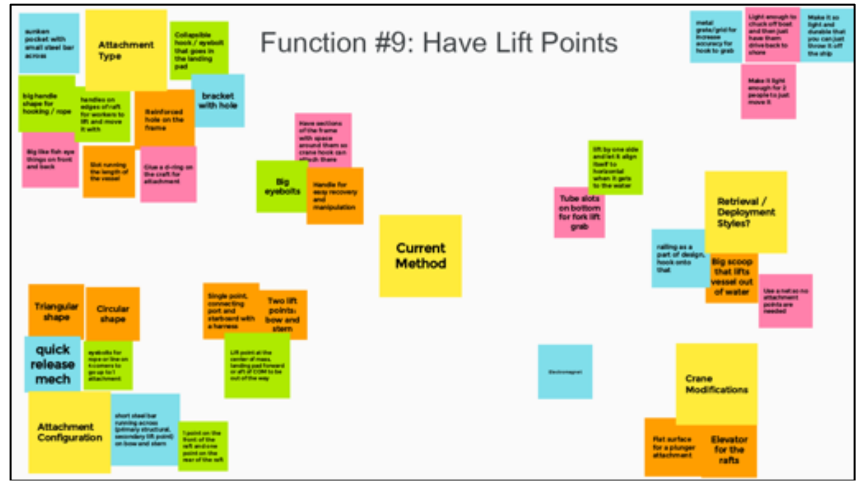

Function #5: Withstand Elements
Sacrificial parts
Aluminum components
Replace components yearly
Don't have rafts
Design raft cheep so it is disposable
Covered storage outside of missions
Peanut butter as a lubricant and protectant
Sacrificial anodes
Stainless steel
UV coating spray
Seal raft in bubble
Remove the ocean for no corrosion
Paint (for uv and corossion)
Anodized / Coated bolts
Remove the sun for no UV
Avoid harmful elements
tarp in storage
Corrosion: Zinc plate
Avoid steel
Tune up twice a year
Good cleaning after use
Instal shade cover over raft
Use plastics that are UV stable
Vaseline coatings
UV reflectant paint/coat

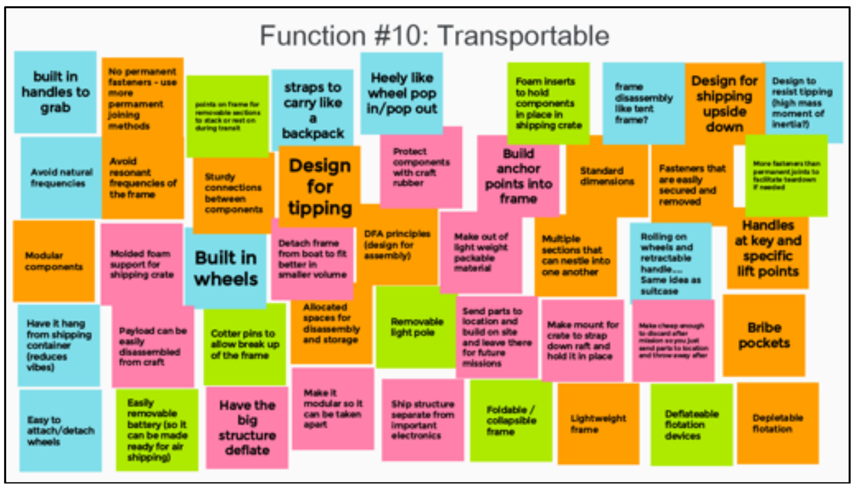

Function #5: Withstand Elements
UV coating spray
Vaseline coatings
Maintenance
Design to be Wet
Material Choice
Avoid steel
Sacrificial Parts
Seal raft in bubble
Cleaning

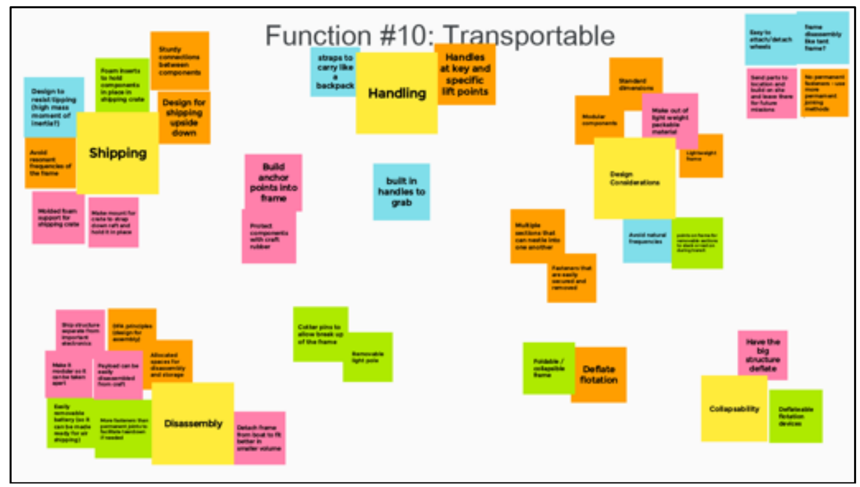

Function #7: Reduce Repair Cost
Longer lifetime parts
Build with higher safety factor
Quick return time on parts
Cheap yet reliable parts
Standard parts
Over design for stress with in reason
Repair manuals
DF Repair, Refurbish
Standard bolts and fasteners
Limit custom parts
Keep things simple
Off shelf parts
Robust parts
Smaller crafts
Robust such that damage is unlikely

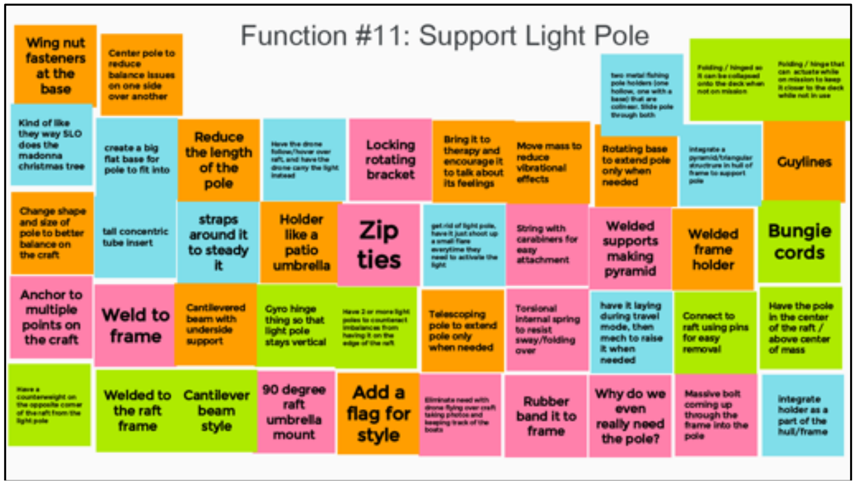

Function #7: Reduce Repair Cost
Robust parts
Durability
Limit custom parts

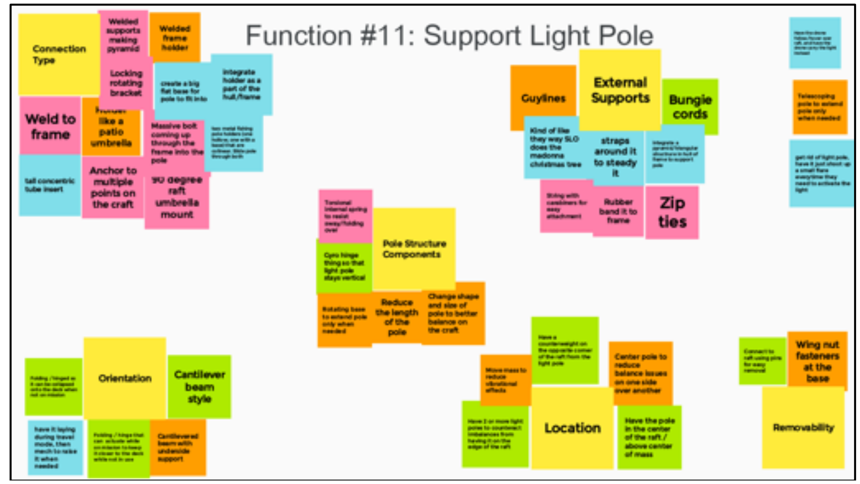

Function #9: Have Lift Points

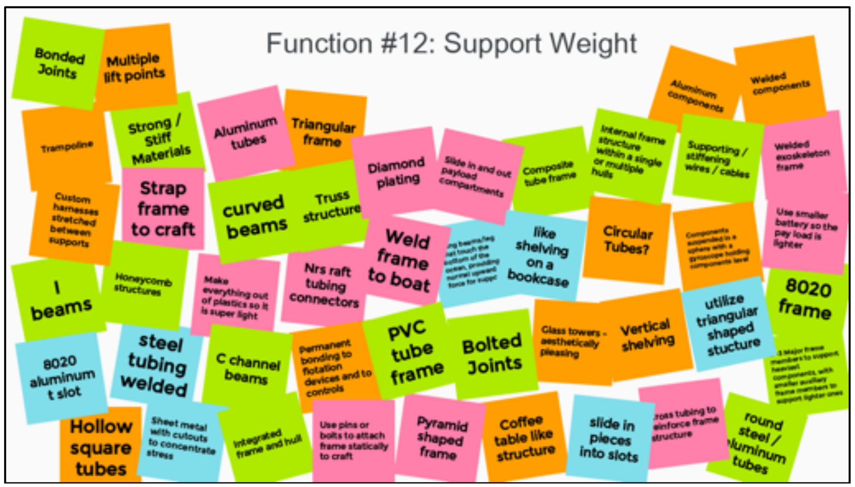

Function #9: Have Lift Points
Attachment Type
Current Method
Retrieval / Deployment Styles?
Attachment Configuration
Crane Modifications

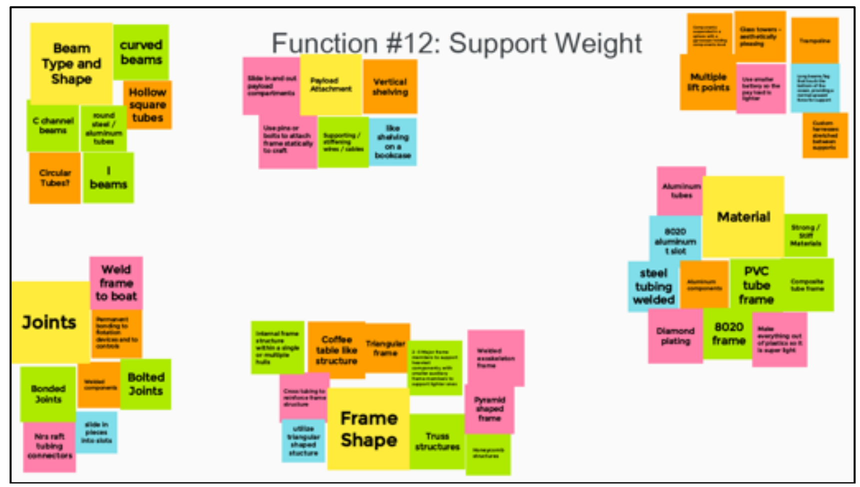

Function #10: Transportable
built in handles to grab
Design for tipping
Built in wheels
straps to carry like a backpack
Heely like wheel pop in/pop out
Design for shipping upside down
Build anchor points into frame
Handles at key and specific lift points
Bribe pockets
Have the big structure deflate


Function #10: Transportable
Shipping
Handling
Disassembly
Collapsability


Function #11: Support Light Pole
Wing nut fasteners at the base
Center pole to reduce balance issues on one side over another
Kind of like they way SLO does the madonna christmas tree
create a big flat base for pole to fit into
Reduce the length of the pole
Locking rotating bracket
Bring it to therapy and encourage it to talk about its feelings
Move mass to reduce vibrational effects
Rotating base to extend pole only when needed
Guylines
Change shape and size of pole to better balance on the craft
tall concentric tube insert
straps around it to steady it
Holder like a patio umbrella
Zip ties
String with carabiners for easy attachment
Welded supports making pyramid
Welded frame holder
Bungie cords
Anchor to multiple points on the craft
Weld to frame
Cantilevered beam with underside support
Cyro hinge thing so that light pole stays vertical
Telescoping pole to extend pole only when needed
Torsional internal spring to resist sway/folding over
Connect to raft using pins for easy removal
Have the pole in the center of the raft / above center of mass
Welded to the raft frame
Cantilever beam style
90 degree raft umbrella mount
Add a flag for style
Rubber band it to frame
Why do we even really need the pole?
Massive bolt coming up through the frame into the pole
integrate holder as a part of the hull/frame

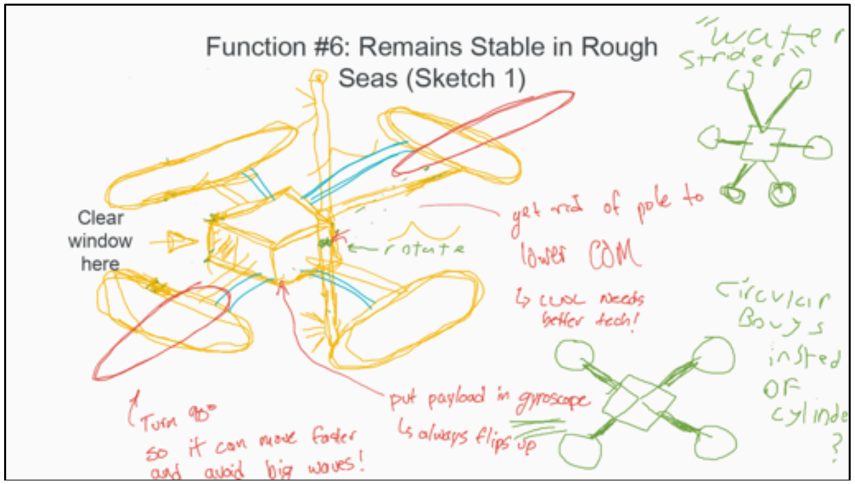

Function #11: Support Light Pole
Connection Type
Weld to frame
Anchor to multiple points on the craft
Guylines
External Supports
Bungie cords
Zip ties
Pole Structure Components
Reduce the length of the pole
Orientation
Cantilever beam style
Location
Wing nut fasteners at the base
Removability

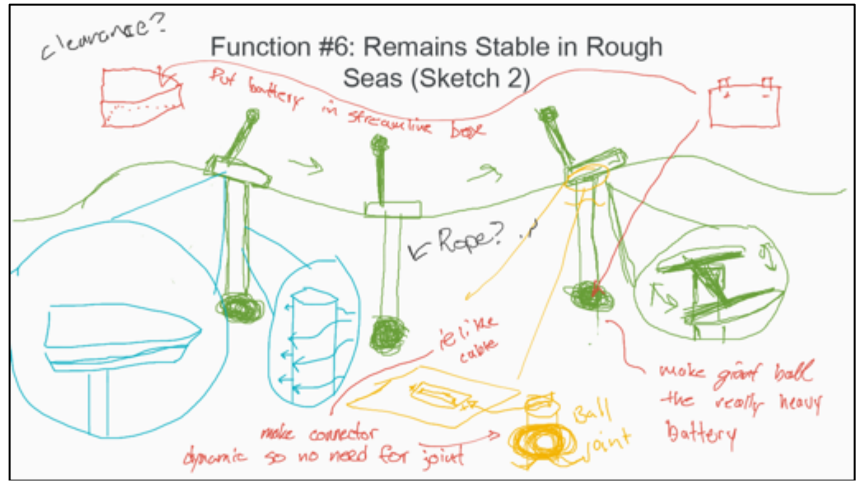

Function #12: Support Weight
Bonded Joints
Multiple lift points
Trampoline
Strong / Stiff Materials
Aluminum tubes
Triangular frame
Diamond plating
Strap frame to craft
curved beams
Truss structure
Weld frame to boat
like shelving on a bookcase
Circular Tubes?
I beams
Nrs raft tubing connectors
PVC tube frame
Bolted Joints
Vertical shelving
utilize triangular shaped structure
8020 frame
8020 aluminum t slot
steel tubing welded
C channel beams
Hollow square tubes
Pyramid shaped frame
Coffee table like structure
slide in pieces into slots
round steel / aluminum tubes

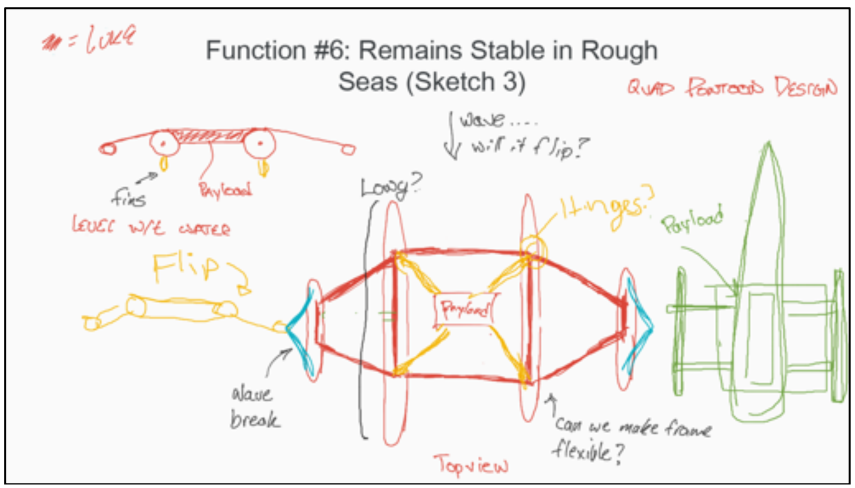

Function #12: Support Weight
Beam Type and Shape
curved beams
Hollow square tubes
I beams
Joints
Weld frame to boat
Bolted Joints
Material
PVC tube frame
8020 frame
Frame Shape

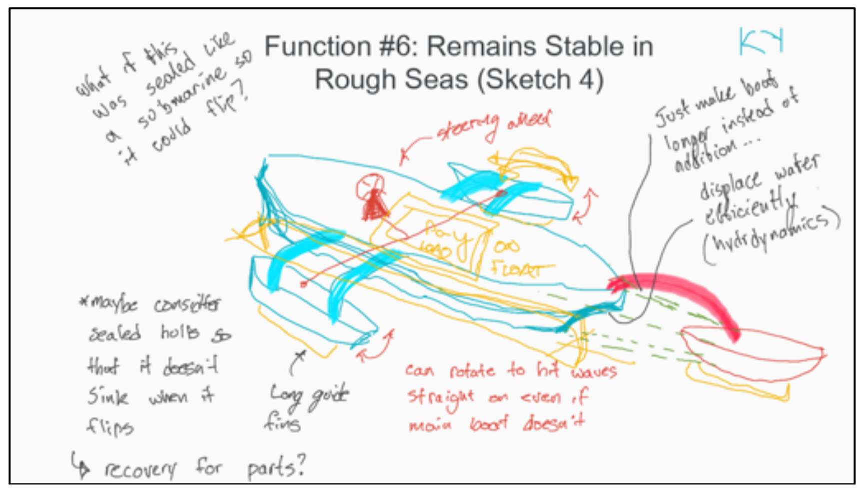
C. Appendix C: Sketching Ideation Results

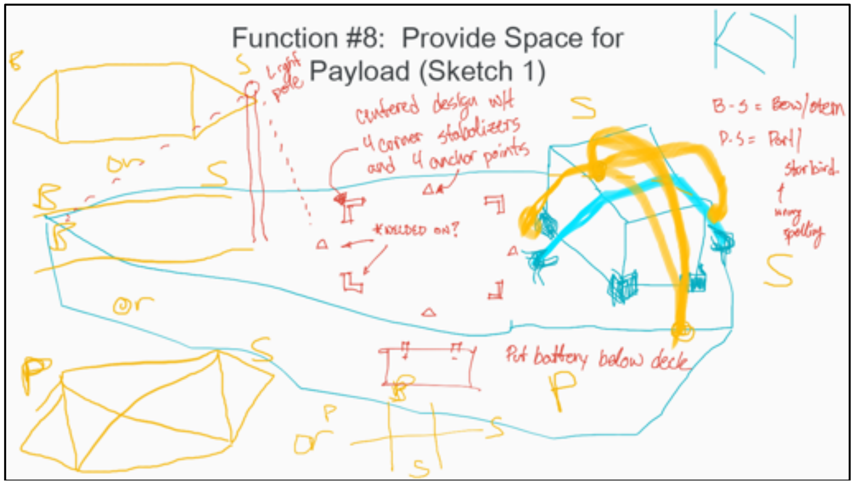
For this ideation technique, we sketched ideas directly in Google Jamboard. Each group member chose a specific color so that we could track changes and additions through the process, allowing all members to better understand how ideas developed over time. Where necessary or applicable, notes are written in black. Each of the two functions for which we used this method has four sketches, one for each member to start.

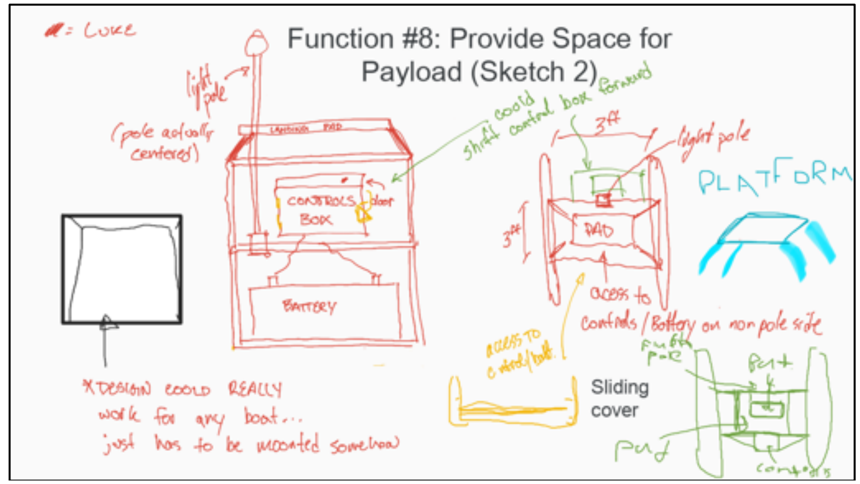


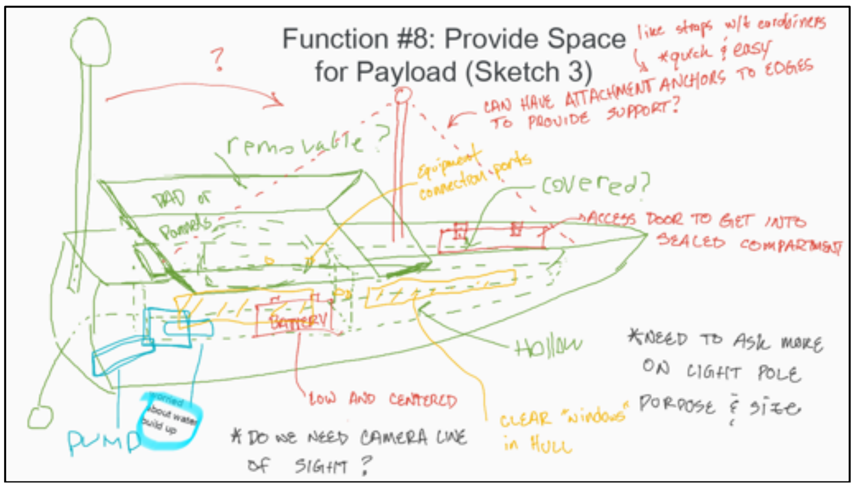


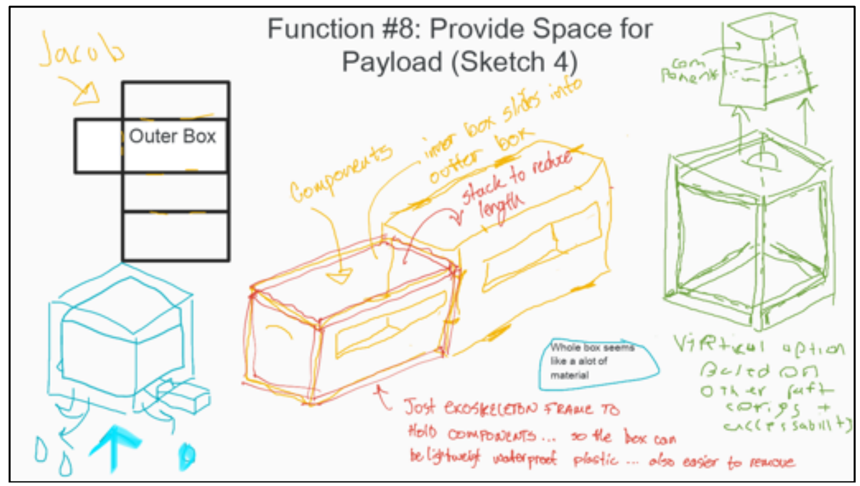





Function #8: Provide Space for Payload (Sketch 1)
Light pole
centered design w/ 4 corner stabilizers and 4 anchor points
*welded on?
B-S = Bow/stern
P-S = Port/Starbird
wrong spelling
Put battery below deck
or

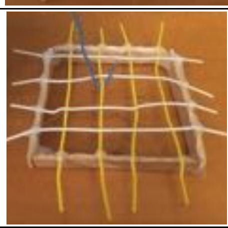

= Luke
Function #8: Provide Space for Payload (Sketch 2)
light pole
(pole actually centered)
could shift control box forward
CONTROLS BOX
door
BATTERY
3ft
light pole
PLATFORM
PAD
access to controls/battery on non pole side
*DESIGN COULD REALLY work for any boat...
just has to be mounted somehow
access to ctrl/batt
Sliding cover
Pad

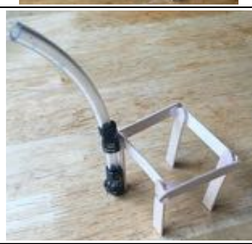

Function #8: Provide Space for Payload (Sketch 3)
like straps w/ carabiners
*quick & easy
CAN HAVE ATTACHMENT ANCHORS TO EDGES TO PROVIDE SUPPORT?
removable?
equipment connection ports
covered?
PAD or Panels
ACCESS DOOR TO GET INTO SEALED COMPARTMENT
BATTERY
Hollow
*NEED TO ASK MORE ON LIGHT POLE PURPOSE & SIZE
LOW AND CENTERED
CLEAR "windows" in HULL
*DO WE NEED CAMERA LINE OF SIGHT?
PUMP


Jacob
Function #8: Provide Space for Payload (Sketch 4)
Outer Box
Components
inner box slides into outter box
stack to reduce length
Whole box seems like a alot of material
Just EXOSKELETON FRAME TO HOLD COMPONENTS... so the box can be lightweight waterproof plastic... also easier to remove
Virtical option
Based on other puft origs + accessability

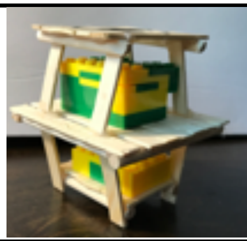
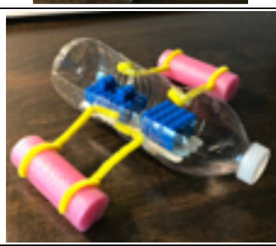
D. Appendix D: Concept Models

Concept Photo	Concept Description	Functions Addressed
	This concept models a foldable frame. The triangular shaped frame components would be able to fold inward, providing a compact design to maximize space capacity.	Stackable Support Weight
	This model shows the concept for a drainage component to divert any water from lingering around the payload. This drip tray would be beneath the payload.	Protect Payload Provide Space for Payload
	This Water Strider explores the possibility of using multiple buoys as a way to keep the craft stable. It also depicts how a payload component could fit into this craft.	Remain Stable in Rough Seas Provide Space for Payload Provide Buoyant Forces
	The photo shows using multiple capped PVC tubes bundled together to provide floatation.	Provide Buoyant Forces
	To support the light pole onto the craft, this bungee cord concept was explored. Tension on the cables would keep the light pole from oscillating.	Support Light Pole

Concept Photo	Concept Description	Functions Addressed
	This model shows a craft standing upright. The idea is to decrease the space it would take up on deck. This method would work well if the center of mass is towards the stern of the craft.	Decrease Footprint Size
	The idea for this concept model is to secure the payload. This idea includes the payload constrained by four corner brackets and contained by two elastic straps.	Provide Space for Payload
	The photo shows using side rails as a point of contact for lifting. This would eliminate the need for a small target hook area.	Have Lift Points
	This idea shows the use of a hook target area that would increase the chances of grabbing onto the craft.	Have Lift Points
	To help with stability of the craft, the use of a dynamic connection to a low hanging mass was explored. The connection tested is a “S” hook	Remain Stable in Rough Seas

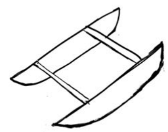
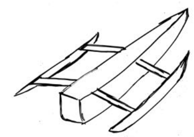
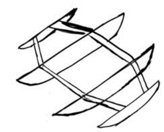
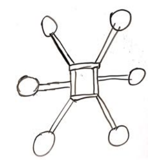
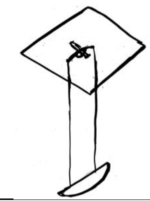
Concept Photo	Concept Description	Functions Addressed
	This model looks at using small side pontoons to help with the stability of the craft. This model also looked at the possibility of rotating the orientation of the small pontoons to help take on waves more head on.	Remain Stable in Rough Seas
	To secure the light pole onto the craft while making it easy to transport, a hinge and bungee cord method was explored. The idea would be that the pole would be lay down in travel mode and then lie upright via bungee cord when needed.	Support Light Pole Transportable
	Model for providing support for the light pole by using two pole holders that are attached to the frame. The light pole would be able to slip in.	Support Light Pole
	To help achieve a smaller footprint, the idea of horizontal folding of some portion of the craft was explored. Here the side pontoons would swing inward to maximize space.	Decrease Footprint Size
	This model looks at the idea of adding a scissor folding component onto the craft to maximize space.	Decrease Footprint Size

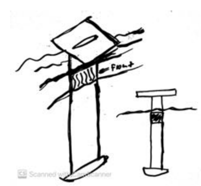
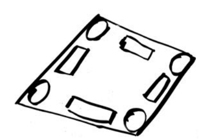
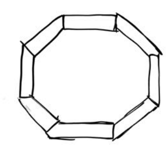
Concept Photo	Concept Description	Functions Addressed
	To minimize the footprint size, the idea of vertical folding was tested. The side pontoons were able to fold over and inward in this model.	Decrease Footprint Size
	This concept of using multiple round buoys around the craft would help with stability and buoyancy.	Remain Stable in Rough Seas Provide Buoyant Forces
	This model looks at using a large keel beneath the craft to help with stability. The keel would be able to rotate along one plane to help keep the craft properly oriented in rough weather.	Remain Stable in Rough Seas
	To explore how to keep the craft afloat, the idea of using multiple buoys was explored. These buoys would be oriented in a way to create an even disbursement of floatation.	Provide Buoyant Forces Remain Stable in Rough Seas
	This model uses two long corks to mimic two pontoons in a catamaran configuration. This helped understand how stable this kind of method may be.	Remain Stable in Rough Seas Provide Buoyant Forces

Concept Photo	Concept Description	Functions Addressed
	To provide a space for the payload and battery, a shelving system was explored. The lower shelf would hold the battery and the middle shelf would hold the payload.	Provide Space for Payload
	This model uses a keel on both floatation components of a catamaran style craft. This was tested to check the stability as well as the turning capabilities of a design like this.	Remain Stable in Rough Seas
	Light pole mount concept model to see how a hinging light pole mount would behave.	Support Light Pole
	To test minimizing footprint on deck, the idea of a flexible trimaran concept model was created. The idea is that the side pontoons would be able to fold over and inward.	Decrease Footprint on Deck
	To explore the feasibility of lifting, a test bed was modeled to simulate varying locations for lift points. In this model, the box could be test lifted from multiple combinations of lift points and observe how stable the box would be.	Have Lift Points

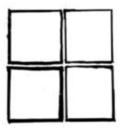
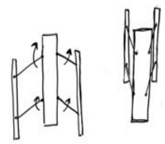
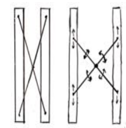
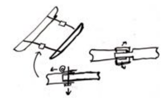
E. Appendix E: Pugh Matrices

Function: Remain Stable

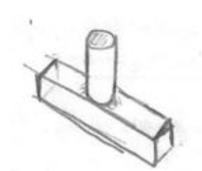
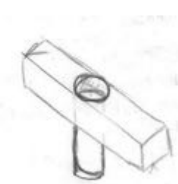
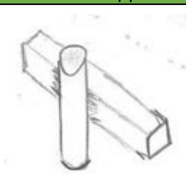
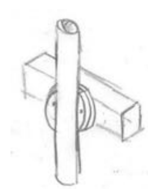
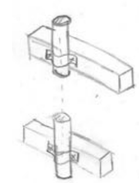
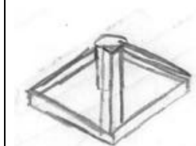
		Catamaran	Monohull	Trimiran	Quadrimaran	Water Strider	Pivoting Keel
	Ideas and Sketches						
Wants/Needs	Stability vs size	S	-	+	S	+	+
	Stability vs weight	S	-	+	-	+	+
	Low CG Height	S	+	S	S	-	+
	Speed (Hydrodynamic)	S	-	S	-	-	-
	Maneuverability	S	+	+	-	+	S
	Few moving parts	S	S	S	S	S	-
	Payload Space	S	-	S	S	-	-
	Ease of Launch / retrieval	S	S	S	S	S	-
	Total 'S' Score	**8**	**2**	**5**	**5**	**2**	**1**

		Dynamic Cable Keel	"Bouy Keel"	Monohull + Solid Keel	Flat Square	Ring
	Ideas and Sketches					
Wants/Needs	Stability vs size	+	+	+	-	-
	Stability vs weight	+	+	+	-	-
	Low CG Height	+	+	+	-	-
	Speed (Hydrodynamic)	-	-	-	-	-
	Maneuverability	-	-	+	S	S
	Few moving parts	-	S	S	S	S
	Payload Space	-	-	-	+	+
	Ease of Launch / retrieval	-	S	S	S	S
	Total 'S' Score	**0**	**2**	**2**	**3**	**3**

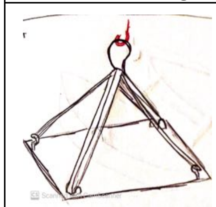
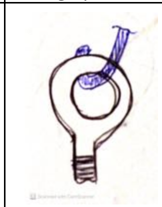
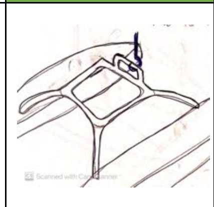
Function: Decrease Footprint Size

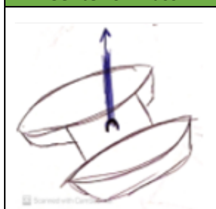
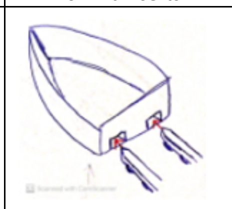
		Efficient Shape	Horizonal Folding	Vertical Folding	Scissor Folding	Rapid Disassembly	Shopping Cart Shape	Stacking	Vertical Storage
	Ideas and Sketches								
Wants / Needs	Few Moving Parts	S	-	-	-	S	S	S	S
	Fast Deployment	S	-	-	-	-	S	-	-
	Space Saving Potential	S	+	+	+	+	+	+	+
	Lightweight	S	S	S	S	S	S	-	-
	Stability on Deck	S	S	-	S	S	S	-	-
	Hydrodynamics	S	S	S	S	S	-	S	S
	Total 'S' Score	**6**	**3**	**2**	**3**	**4**	**4**	**2**	**2**

Function: Support Light Pole

		Simple Cantilever	Integrated Holder	Welded Support	Rotating Hinge	Colinear Supports	Guylines	Pyramid Frame
	Ideas and Sketches							
Wants / Needs	Easily Shippable	S	S	S	+	+	S	S
	Uses Standard Materials	S	-	S	-	+	-	-
	Uses Standard Fasteners	S	S	S	S	+	S	S
	Short Field Assembly Time	S	S	S	+	-	-	S
	Stackable	S	+	+	+	S	S	-
	Lightweight	S	S	S	-	S	+	-
	Total 'S' Score	**6**	**4**	**5**	**1**	**2**	**3**	**3**

Function: Have Lift Points

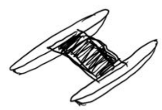
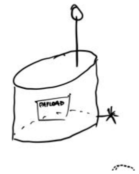
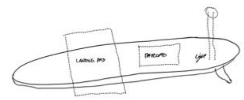
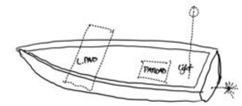
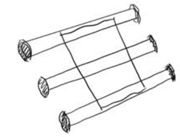
		LLNL Current Design	Big Eyebolt	Hook onto frame	Port and Starboard Single Point	Bow and Stern Lifts
	Ideas and Sketches					
Wants / Needs	Easy Retrieval	S	-	-	S	-
	Easy Deployment	S	-	+	+	+
	Field Assembly Time/Prep	S	+	+	+	+
	Drone compatible	S	+	+	S	+
	Standard Equipment/Parts	S	+	+	S	S
	Total 'S' Score	**5**	**0**	**0**	**3**	**1**

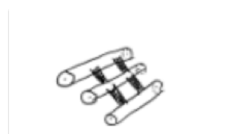
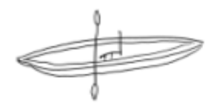
		Center of Mass	Electromagnet	Forklift Inserts	Single Point: Side	Handles
	Ideas and Sketches					
Wants / Needs	Easy Retrieval	-	+	-	-	-
	Easy Deployment	+	+	-	+	+
	Field Assembly Time/Prep	+	+	-	+	+
	Drone compatible	S	S	+	-	+
	Standard Equipment/Parts	S	-	-	+	+
	Total 'S' Score	2	1	0	0	4

Function: Transportable

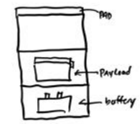
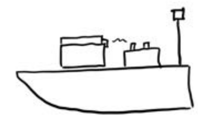
	Ideas and Sketches	Current Raft	Build anchor points into frame	Protect components with craft rubber	Cotter pins to break up	Removable light pole	Foldable / collapsible frame	Deflate floatation	Easy to secure / remove fasteners	Sections nestle into each other	Built in Handles
Wants / Needs	Weight	S	S	S	S	S	S	S	S	S	S
	Efficient Assembly/handling	S	+	-	-	S	-	-	-	+	+
	Drone Pad compatibility	S	+	S	-	+	-	-	S	+	+
	Few Moving Parts	S	+	-	-	S	-	S	S	+	+
	Space Efficient	S	S	+	+	+	+	+	+	+	S
	Total 'S' Score	**5**	**2**	**2**	**1**	**3**	**1**	**2**	**3**	**1**	**2**

Function: Provide Buoyancy Forces

		Current Rubber Pontoon	Round Buoy	Foam Board	Aluminium Boat	Capped PVC Pipes
	Ideas and Sketches					
Wants / Needs	Lightweight	S	+	+	-	+
	Easily Shippable	S	+	+	-	+
	Drone Pad compatibility	S	-	S	S	S
	Resistant to Corrosion	S	S	S	S	S
	Top Speed (5mph)	S	-	+	S	-
	Stackable	S	-	S	-	S
	Payload Weight	S	-	-	S	-
	Total 'S' Score	**7**	**1**	**3**	**4**	**3**

		Rubber Raft	Linked Inner Tubes	Foam Carved Boat	Pre Fab Kayak
	Ideas and Sketches				
Wants / Needs	Lightweight	-	+	S	S
	Easily Shippable	-	S	-	-
	Drone Pad compatibility	S	S	S	-
	Resistant to Corrosion	S	S	+	+
	Top Speed (5mph)	-	-	S	+
	Stackable	+	S	-	S
	Payload Weight	S	-	-	-
	Total 'S' Score	3	4	3	2

Function: Provide Space for Payload

	Ideas and Sketches	Current Frame with Metal Box	Below Deck in Hull	Exoskeleton frame w/t boxes	Mounted to deck surface	Payload structure is boat
						
Wants / Needs	Lightweight	S	+	S	+	+
	Easily Shippable	S	+	+	+	-
	Drone Pad compatibility	S	+	+	-	S
	Resistant to Corrosion	S	+	S	-	S
	Standard Fabrication	S	-	+	+	-
	Stackable	S	S	+	-	-
	Payload Weight	S	S	S	S	S
	Total 'S' Score	**7**	**2**	**3**	**1**	**3**

Function: Translate and Rotate the Vessel

	Ideas and Sketches	Fixed Trolling Motors	Full Trolling Motors	RC Boat Motors	Thrusters	Rudders	Water Jet Propulsion	Paddle Wheel
Wants / Needs	Lightweight	S	-	+	S	-	-	-
	Differential Motor Steering	S	+	-	+	-	-	-
	Long Mission Time	S	S	+	S	+	-	-
	Uses Standard Material	S	S	-	S	-	-	-
	Total 'S' Score	**4**	**2**	**0**	**3**	**0**	**0**	**0**

F. Appendix F: Morphological Matrix

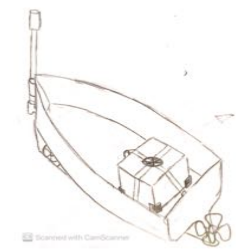
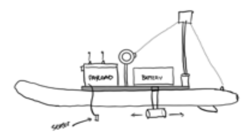
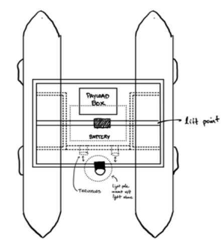
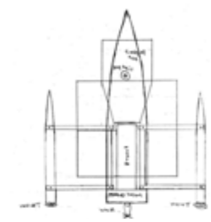
Concept Option 1 is the Aluminum Monohull in Figure 17.
Concept Option 2 is the Surfing Raft in Figure 18.
Concept Option 3 is the Rubber Catamaran in Figure 19.
Concept Option 4 is the Folding Trimaran – Rubber in Figure 20.
Concept Option 5 is the Folding Trimaran – Fiberglass in Figure 21.
Concept Option 6 is the Water Strider in Figure 22.
Concept Option 7 is the Telescoping Trimaran in Figure 23.
Concept Option 8 is the Truss Catamaran in Figure 24.

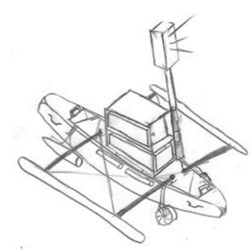
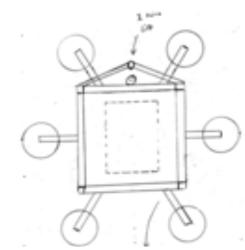
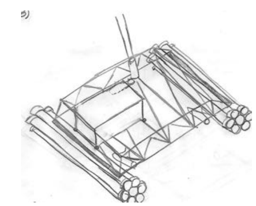
Attribute/Function	Ideas For Function					
Remain Stable	Catamaran	Trimiran	Water Strider	"Buoy Keel"	Monohull + Keel	
Decrease Footprint Size	Shopping Cart	Stacking	Horizontal Folding	Rapid Dissassembly	Efficient Shape	
Space For Payload	Below Deck in Hull	Mounted to Deck	Exoskelleton w/t boxes	Payload becomes the hull		
Provide Bouyant Forces	Rubber Tube	Fiberglass Reinforced Foam	Aluminium Hull	Foam Board	Capped PVC Pipes	Round Rubber Bouys
Support Light Pole	Colinear Storage and Support	Cantilever with ropes	Cantilever and Welded Storage	Current Cantilever Solution	Mounted Support	
Translate/Rotate	All Thrusters	Rotating Motors	Thrusters and Motor Combinations	Motors in a specialized configuration	Thrusters in a specific configuration	
Have Lift Points	Hook onto Frame	P and S Strap Single Lift	Bow and Stern Hook Lift	Center of Mass		
Transportable	Build anchor points into frame	Protect component with craft rubber	Removable light pole	Foldable/collapsible Frame	Sections Nestle into Eachother	Built in Handles
Frame Shape	Truss Structure	Primary Members, Secondary Members	Pyramid Frame	Honeycomb Compartments	Internal Frame	
Payload Attachment	Slide in and out of Payload Compartment	Stiffining wire/cable for support	Shelving	Use bolt/pins to attach to frame		

Concept	1	2	3	4	5	6	7	8
Remain Stable	Monohull+Keel	"Monohull"	Catamaran	Trimiran	Trimiran	Water Strider	Trimiran	Catamaran
Decrease Footprint Size	Efficient Shape	efficient shape	Stacking	Horizontal Folding	Horzontal Folding	Stacking / Efficient Shape	Shopping Cart	Stacking
Space For Payload	Below deck in hull	mounted to deck	Exo with boxes	Exoskelleton w/t boxes	Mounted to deck	Exo with boxes	Mounted to Deck	Mounted to Deck
Provide Bouyant Forces	Aluminium Hull	Flat foam board	Rubber Tube	Rubber Tube	Fiberglass / Foam hulls	Round Rubber Bouys	Fiberglass/foam + Rubber Tube	Capped PVC Pipes
Support Light Pole	Cantilever and Welded Storage	cantilever w/t rope	Mounted Support	Colinear Storage and Support	Colinear Storage and Support	Mounted Support	Colinear Storage and Support	Cantilever and Welded Storage
Translate/Rotate	Thrust and motor combo with rudder	thrusters	All Thrusters	Thrusters and Motor Combinations	Thrusters and Motor Combinations	Motors	Thruster and Motor Comb.	Motors in a specialized configuration
Have Lift Points	Center of Mass	center of mass	Hook onto Frame	Bow and Stern Hook Lift	Undecided	Hook onto Frame	Hook Onto Frame	Hook onto Frame
Transportable	Sections Nestle into Eachother	anchor points / foldable pole	anchorpoints / removable pole	Built in Handles and Removable light pole	Foldable / collapsible Frame	Foldable / collapsible Frame	Foldable / collapsible frame	Foldable / collapsible frame
Frame Shape	Internal Frame	P. mem/S.mem	P. mem/S. mem	Primary Members, Secondary Members	P. mem / S.mem	P. mem / S.mem	Primary and Secondary	Truss Structure
Payload Attachment	Stiffining wire/cable for support	bolts/pins	Slide in and out	Shelving	bolts/pins	Shelving	Shelving	Use bolt/pins to attach to frame

G. Appendix G: Weighted Decision Matrix

Concept option characteristics are detailed in Appendix F.

Criteria	Spec	Weighting	Concept Options							
			1		2		3		4	
										
			Score	Total	Score	Total	Score	Total	Score	Total
Weight	200lb	14%	3	0.42	5	0.7	4	0.56	2	0.28
Payload	10lb	13%	4	0.52	2	0.26	5	0.65	4	0.52
Field Assembly Time	<5min	10%	3	0.3	2	0.2	4	0.4	2	0.2
Footprint on Deck	4'x7'	9%	3	0.27	4	0.36	3	0.27	3	0.27
Cost to Manufacture	$15,000	9%	2	0.18	2	0.18	3	0.27	3	0.27
Number of Motors	2 Motors	8%	4	0.32	4	0.32	5	0.4	3	0.24
Stability	3ft	8%	3	0.24	0	0	3	0.24	3	0.24
Shipping Dimensions	6'x6'x6'	7%	4	0.28	3	0.21	4	0.28	3	0.21
% Purchased Parts	80%	7%	2	0.14	2	0.14	3	0.21	3	0.21
Speed	5 ft/s	6%	4	0.24	5	0.3	4	0.24	4	0.24
Battery Life	2 days	3%	2	0.06	5	0.15	3	0.09	2	0.06
Points of Contact	2 Points	3%	4	0.12	5	0.15	4	0.12	3	0.09
Waterproof	Yes	3%	2	0.06	1	0.03	3	0.09	4	0.12
SUM			6.3		6		**7.64**		5.90	

Criteria	Spec	Weighting	Concept Options							
			5		6		7		8	
										
			Score	Total	Score	Total	Score	Total	Score	Total
Weight	200lb	14%	3	0.42	3	0.42	3	0.42	1	0.14
Payload	10lb	13%	4	0.52	4	0.52	4	0.52	5	0.65
Field Assembly Time	<5min	10%	2	0.2	4	0.4	2	0.2	4	0.4
Footprint on Deck	4'x7'	9%	3	0.27	4	0.36	3	0.27	3	0.27
Cost to Manufacture	$15,000	9%	2	0.18	3	0.27	2	0.18	2	0.18
Number of Motors	2 Motors	8%	3	0.24	1	0.08	4	0.32	5	0.4
Stability	3ft	8%	4	0.32	4	0.32	3	0.24	3	0.24
Shipping Dimensions	6'x6'x6'	7%	3	0.21	5	0.35	3	0.21	4	0.28
% Purchased Parts	80%	7%	2	0.14	2	0.14	2	0.14	4	0.28
Speed	5 ft/s	6%	4	0.24	3	0.18	4	0.24	2	0.12
Battery Life	2 days	3%	3	0.09	2	0.06	3	0.09	1	0.03
Points of Contact	2 Points	3%	3	0.09	5	0.15	3	0.09	1	0.03
Waterproof	Yes	3%	3	0.09	3	0.09	4	0.12	3	0.09
SUM			6.02		6.68		6.08		6.22	

Concept Design Analysis

Concept 1: Concerns with this monohull design is the stability. Traditionally, multihulls are more stable. When considering the smaller scale size of this project, stability is an important factor. Some other concerns for this design would be accounting for drone pad. One strong point of this design is the use of the thrusters and motors.

Concept 2: This design encompasses a simple foam reinforced board to provide buoyant forces. Because of this, some strong points for this design is the fact that it is lightweight and doesn't take up much space. Similarly, because it is very light, it would be able to reach the desired speed. The biggest design flaw is the lack of stability.

Concept 3: This catamaran pontoon design adequately met many of our specifications—by this, the design received multiple threes and fours. The only drawback is the weight of this design, thus creating issue with the battery life. One thing we noticed was that it is very similar to LLNL's current raft.

Concept 4: This strongest quality of this trimaran style is the number of motors it incorporates. However, because of this, the battery life would be an issue. Otherwise, it received average marks for the other criteria. Field assembly time was a weakness, the idea is that the side pontoons would detach to achieve a smaller footprint, but in turn would increase the assembly time. This design also is one of the more stable designs.

Concept 5: This trimaran style also adequately met many of our design criteria. Because of its streamline shape, it earned a high mark in the speed category. One unique feature of this design is the foldability of the side pontoons. Though this creates a smaller footprint on deck, it sacrifices a low field assembly time.

Concept 6: The topic of stability was a hot topic for this concept design. We were worried about the six round buoys providing enough buoyant forces for the metal frame. However, we acknowledge that this design would be the most compact and transportable—this design ranked higher in any criteria related to size. One issue that came up was the design is not very hydrodynamic and would in turn drain battery life and not be as fast as needed.

Concept 7: This design was another trimaran design. The idea with this one included fiberglass reinforced foam. this means it scored low in cost to manufacture and purchased parts. It received average marks for the majority of the criteria.

Concept 8: This design was different from the other designs. It utilizes multiple capped PVC pipes as floatation and a strong rigid frame. This design is clearly the heaviest of all the designs and therefore received low marks for criteria that has a relationship to weight such as speed and battery life. Despite this, the design is meant to be made from off the shelf parts and minimize customization.

Final Design Direction Discussion

The team went through the rankings of each category for each design and tweaked the rankings

Weight – reconsidered the weight of pontoons, (lighter than expected) so naturally, those with buoys ranking went up.

Payload– the criteria is to meet 10lbs, which they all do, but would it hold the battery? Considering this, there was heavy changes to the ranking.

Field assembly time – light pole and payload = 3 plus foldability = 2 just light pole or just payload = 4

Footprint on deck – We looked at if the design is stackable and how much room they take up and how well they can play Tetris on the deck

Cost to manufacture – how custom is the design? Designs that ranked lower included fiberglass reinforced foam.

Motors – While a lot of them meet the goal of having at least two motors, we also wanted to consider the feasibility of attaching the motors to the design. Less feasible motor attachments would lower ranking

Stability – Considering how wide the design is and how low the CG is

Shipping dimensions – They all meet the 6x6x6 so we took into consideration the smaller want goal of 4x4x3 and how well they could potentially meet that as well

Purchased parts – what are they exactly... anything you can simply go to a store and pick up

Speed – looked at how hydrodynamic the design was. Typically, if a design was heavy, they would be less speedy. Similarly, if the design had less motors, they would also be slower.

Battery life – lower ranking for non-hydrodynamic designs. Also considering how thrusters and motors effect battery life. Those with motor rank lower for battery life

Points of contact – those that have one lift point, ranked higher. If when raising, it is unstable it ranks 4. If use two lift points and stable > 3. If two lift points and not that stable >2

Waterproof – Reevaluated the criteria more to “potentially for payload to get wet” and “potential for payload to stay wet

Before taking a look at the ratings (without changing the relative weights at the moment) we are very surprised that trimarans ranked some of the lowest.... Looking at the relative weights, we thought maybe that we didn’t capture the voice of the customer that well the QFD. We talked about tweaking the QFD to adjust the relative weights...But we realized that even if we mess around with the weight, concept 3 is still the clear winner. The next steps include highlighting positives of other concepts so we can hopefully integrate that into concept 3. Similarly, we are talking about disadvantages of concept 3.

Advantaged from other concepts:

- \- From monohull aluminum – protecting the payload
- \- From spider – 360 deg stability, shippable + compacted center
- \- Concept 8 – deconstruct easily
- \- Sleek trimaran – hydrodynamic so potentially implement for cat (maybe calculate the drag from the rubber)

Disadvantages of concept 3

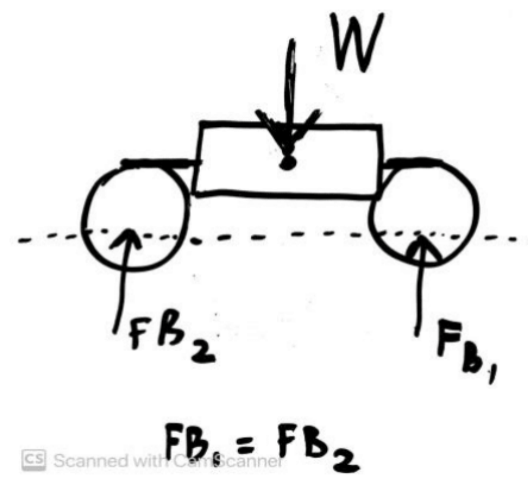
- \- How stackable is it really?
- \- Round objects (pontons) on flat surfaces during rough seas may create wear. Potentially strap them down when stacked on deck or even try Lego acceptance method such that they fit together better.
- \- It looks like their current one.
- \- Air chambers will expand and contract due to weather and what not, how can we accommodate for pressure changes in the pontoon
- \- Also consider, metal expansion and contraction
- \- Wear and tear on from metal on rubber causes minor damage
- \- Sun exposure does the most damage on the rubber
- \- Could fit more thrusters on design
- \- Could maybe mimic motor configuration

H. Appendix H: Concept Prototype

I. Appendix I: Preliminary Buoyancy Calculations

PRIMARY VESSEL SPECS.

Wf	200	lbf	Raft weight (frame, pontoons, motors, etc)
Wb	136	lbf	battery weight
Wp	10	lbf	payload weight (removable payloads from box)
Wtotal	346	lbf	Total weight (= total boyant force)
rho	62.4	lbf/ft^3	Density of water
Vsub	5.54	ft^3	Total Submerged volume
Vsub1	2.77	ft^3	submerged volume of one pontoon



Assumes a cylindrical pontoon with flat ends

PONTOON SPECS

L (ft)	OD (in)	R (in)	V (ft^3)	Asub (ft^2)
7	15	7.5	8.25	0.396

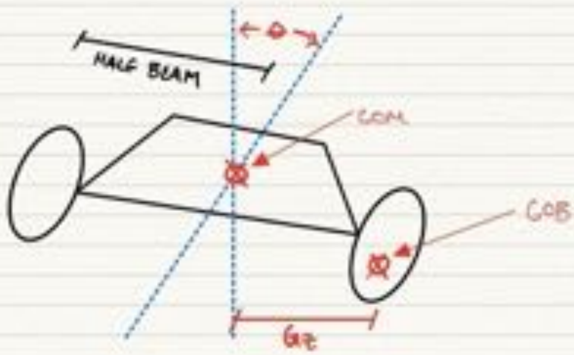
SumFy = -W + FB1 + FB2 = 0

W = FB1+FB2

W = FBtotal

J. Appendix J: Preliminary Stability Calculations

INITIAL STABILITY CALCULATIONS



$Gz = \text{HALF BEAM} * \cos(\theta)$

RIGHTING MOMENT: $R_m = Gz * F_{WEIGHT}$

The righting moment will provide an estimation for how much rotational energy it will take to flip the craft.

$$E_{ROT} = \frac{1}{2} * I * \omega^2$$

* ω can be found from wave properties like height and frequency.

* By solving for the rotational moment of inertia and the righting moment of the craft we will be able to solve for an estimated stable wave conditions the raft will be able to navigate.

* IT SHOULD BE NOTED THAT THE RECOMENDED TO AVOID DANGER WAVE SITUATIONS DEPICTED BELOW:

WAVE HEIGHT > BOAT LENGTH * 30%

WAVE LENGTH ≤ WAVE HEIGHT * 7

K. Appendix K: Design Hazard Checklist

Y	N	Proposed Hazard
X		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
	X	2. Can any part of the design undergo high accelerations/decelerations?
X		3. Will the system have any large moving masses or large forces?
	X	4. Will the system produce a projectile?
X		5. Would it be possible for the system to fall under gravity creating injury?
X		6. Will a user be exposed to overhanging weights as part of the design?
	X	7. Will the system have any sharp edges?
X		8. Will any part of the electrical systems not be grounded?
X		9. Will there be any large batteries or electrical voltage in the system above 40 V?
X		10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	X	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	X	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
X		13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	X	14. Can the system generate high levels of noise?
X		15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
X		16. Is it possible for the system to be used in an unsafe manner?
	X	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Electric motors will provide thrust to the craft.	Guards will be utilized around the rotating blades such that injury can be minimized.	02/12/21	04/01/21
The craft will be lifted from the launching vessel into the ocean by crane.	Launching vessel will have protocol for launching craft but additional recommended safe practices will be provided in user manual.	06/04/21	05/13/21
The craft will have a lift point for the crane to attach which will result in higher forces in a concentrated area when lifting.	Stress analysis will be performed on the frame structure to minimize the chance of frame failure under loading due to lifting from the crane.	02/12/21	02//23/21
A large battery will power the components integrated on the craft.	Sufficient warning labels and instructions will be utilized to inform users of dangers regarding the battery and safe practices to minimize risk.	06/04/21	05/13/21
The craft will be operating out in the open ocean exposing it to extreme environmental conditions.	Components will be designed with materials that do not degrade in these conditions such that the function of the craft will not become jeopardized due to environmental exposure. Additional documentation will be provided describing maintenance procedures to additionally aid in reducing hazards caused by the environment.	06/04/21	05/13/21
The overall system has the potential to be used improperly and cause harm to others or the user in the water.	An intended use and practices will explicitly describe the function and intended use of the craft such that the user understands how to operate safely and minimize the risks that come from it being used improperly.	06/04/21	05/13/21

L. Appendix L: Intended Bill of Materials

Research Raft

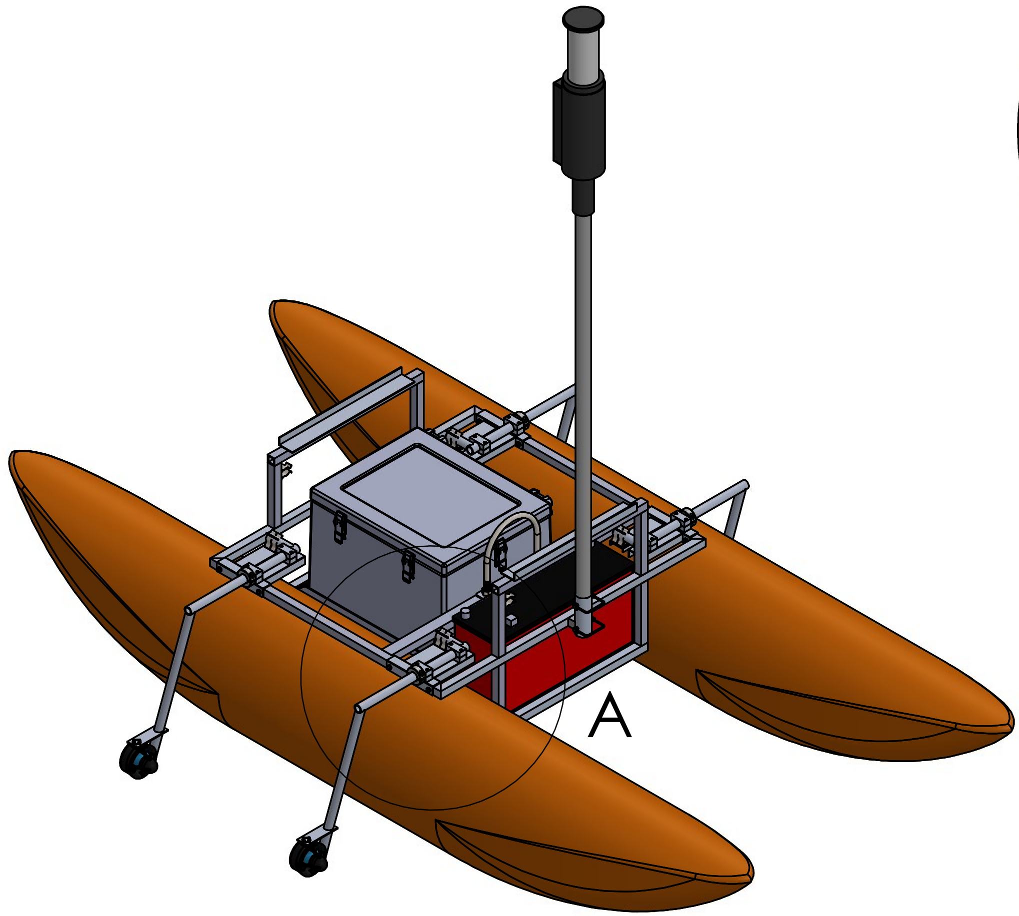
Indented Bill of Material (iBOM)

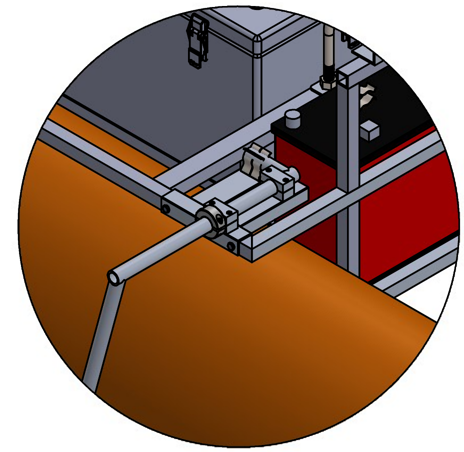
Assembly Level	Part Number	Description (Lvl0 Lvl1 Lvl2 Lvl3 Lvl4)	Qty	Cost	Ttl Cost	Source	Source Part Number	More Info
0	100.00	Final Assembly	1	--	--	------	------	------
1	110.00	Frame Assembly	1	--	--	------	------	------
2	111.00	Frame Subassembly	1	--	--	------	------	* Frame cost is estimated off $8.50 per foot of tubing and rounded to the nearest foot
3	111.1A	Main Deck Length	2	$7.48	$14.96	Metals Depot	T3118-6061	Al. Square Frame Member - 34" Angled Ends with holes for motor mounts
3	111.1B	Main Deck Width	2	$8.58	$17.16	Metals Depot	T3118-6061	Al. Square Frame Member - 39" Angled Ends with single drain hole
3	111.1C	Lower Deck Length	2	$7.48	$14.96	Metals Depot	T3118-6061	Al. Square Frame Member - 34" Angled Ends
3	111.1D	Lower Deck Width	2	$4.84	$9.68	Metals Depot	T3118-6061	Al. Square Frame Member - 22" Angled Ends
3	111.2A	Vertical Riser Bars	10	$1.76	$17.60	Metals Depot	T3118-6061	Al. Square Frame Member - 8" Flat Ends
3	111.2B	Upper Deck Width	2	$4.84	$9.68	Metals Depot	T3118-6061	Al. Square Frame Member - 22" Flat Ends
3	111.30	Flash Pole Member	1	$2.00	$2.00	Metals Depot	T3118-6061	Al. Square Frame Member - 1" Flat End on one side with other being female for light pole connection
3	111.40	Main Deck Lift Member	1	$16.26	$16.26	Metals Depot	T3118-6061	Al. Rect Frame Member - 37" Flat Ends with holes for U bolt
3	111.5A	Upper Deck Stacking Support	2	$1.80	$3.60	Metals Depot	A3211218-6061	Al. Angle Member - 18" Flat Ends
3	111.5B	Lower Deck Payload Box Supports	2	$2.00	$4.00	Metals Depot	A3211218-6061	Al. Angle Member - 20" Flat Ends with 2 mounting holes for payload box
3	111.5C	Lower Deck Battery Supports	2	$2.00	$4.00	Metals Depot	A3211218-6061	Al. Angle Member - 20" Flat Ends with 2 mounting slots for battery straps
3	111.60	U Bolt Mount Plate	2	$5.00	$10.00	Metals Depot		Al. Sheet Metal - 1.5"x8" x.1" Thick Bar with holes for for U bolt
3	111.70	U Bolt	1	$47.82	$47.82	McMaster	29605T13	Comes with 4 stainless steel nuts
3	111.80	Flash Pole Mounting Tube	1	$5.66	$5.66	Online Metals	4365	1.75" OD x 0.065" Wall x 1.62" ID Aluminum Round Tube 6061-T6-Drawn - 5" long
3	111.90	Flash Pole Storage Clips	2	$5.13	$10.25	SeaLux	SL2939L	SeaLux Pair Stainless Steel Boat Hook Spring Clamp Holder Bracket Clip opeing 1"-1-3/4" (Large)
2	112.00	Motor Attachment Left	2	--	--	------	------	
3	112.10	Motor Mount Mounting Bolt	2	$0.58	$2.33	Fastenal	172248	1/4-20 x 1 5/8" Hex Bolt
3	112.20	Motor Mount Mounting Nut	2	$0.45	$1.81	Fastenal	77860	1/4-20 Ny-Lock Nut (2)
3	112.30	Motor Mount - Left	1	--	--	------	------	
4	112.31	Frame Mount	1	$3.48	$6.96			1.25" x 1.25" x 0.125" 6063-T52 Aluminum Channel
4	112.32	Holder Extension	1	$2.40	$4.80			2" x 1" x 0.125" Aluminum Channel 6063-T52
4	112.33	Clip Extension	1	$4.64	$9.28			2" x 0.5" x 0.125" 6063 Aluminum Channel
4	112.34	Top Holder	1	--	--	Custom		Xometry
4	112.35	Bottom Holder	1	--	--	Custom		Xometry
4	112.36	Holder Socket Screw	4	$0.81	$6.50	Fasetnal	79014	#8-32 x 3/4" ASTM F837 Hex Drive Grade 316 Stainless Steel Socket Cap Screw
4	112.37	Clip Screw	4	$0.23	$1.85	Fastenal	178569	#6-32 x 3/8" Phillips Drive Pan Head Grade 316 Stainless Steel Machine Screw
4	112.38	Clip Nut	4	$0.37	$2.97	Fastenal	77855	#6-32 Grade 316 NM Stainless Steel Nylon Insert Lock Nut
4	112.39	Clip	1	$6.99	$13.98	Amarine Made	615200851446	Amarine Boat Spring Clip (set of two)
3	112.40	Motor Arm - Left	1	------	------	------	------	
4	112.41	Arm A	1	$1.20	$2.40	Custom		1" OD x 0.125" Wall x 0.75" ID Aluminum Round Tube cut to 3.5 "
4	112.42	Arm B	1	$5.47	$10.94	Custom		1" OD x 0.125" Wall x 0.75" ID Aluminum Round Tube cut to 16"
4	112.43	Arm C	1	$8.03	$16.06	Custom		1" OD x 0.125" Wall x 0.75" ID Aluminum Round Tube cut to 23.5"
4	112.44	Shaft Collar	1	$13.94	$27.88	McMaster	60485K69	
4	112.45	Tube End Cap	1	$4.61	$9.22	McMaster	9275K142	0.125" Thick Sheet Aluminum 6061
4	112.46	Motor Arm Plate - Left	1	$0.97	$1.94	Custom		
3	112.50	Thruster Screw	4	$0.03	$0.23	Fastenal	QM2510008A20000	M3x0.5 8mm Pan Head Stainless Steel Machine Screw
3	112.60	Thruster Lock Washer	4	$0.03	$0.24	Fastenal	ML6330000A20000	M3 DIN 127 A2 Stainless Steel Split Lock Washer
3	112.70	Thruster	1	$179.00	$358.00	Blue Robotics	T200-THRUSTER-R1-RP	Blue Robotics T200 Thruster
2	113.00	Motor Attachment Right	2	--	--	------	------	
3	112.10	Motor Mount Mounting Bolt	2	$0.58	$2.33	Fastenal	172248	1/4-20 x 1 5/8" Hex Bolt
3	112.20	Motor Mount Mounting Nut	2	$0.45	$1.81	Fastenal	77860	1/4-20 Ny-Lock Nut (2)
3	113.30	Mount Mount - Right	1	--	--	------	------	
4	112.31	Frame Mount	1	$3.48	$6.96	Custom		1.25" x 1.25" x 0.125" 6063-T52 Aluminum Channel
4	112.32	Holder Extension	1	$2.40	$4.80	Custom		2" x 1" x 0.125" Aluminum Channel 6063-T52
4	112.33	Clip Extension	1	$4.64	$9.28	Custom		2" x 0.5" x 0.125" 6063 Aluminum Channel
4	112.34	Top Holder	1	--	--	Custom		Xometry
4	112.35	Bottom Holder	1	--	--	Custom		Xometry
4	112.36	Holder Socket Screw	2	$0.81	$3.25	Fasetnal	79014	#8-32 x 3/4" ASTM F837 Hex Drive Grade 316 Stainless Steel Socket Cap Screw
4	112.37	Clip Screw	4	$0.23	$1.85	Fastenal	178569	#6-32 x 3/8" Phillips Drive Pan Head Grade 316 Stainless Steel Machine Screw
4	112.38	Clip Nut	4	$0.37	$2.97	Fastenal	77855	#6-32 Grade 316 NM Stainless Steel Nylon Insert Lock Nut
4	112.39	Clip	1	$6.99	$13.98	Amarine Made	615200851446	Amarine Boat Spring Clip (set of two)
3	113.40	Motor Arm - Right	1	------	------	------	------	
4	112.41	Arm A	1	$1.20	$2.40	Custom		1" OD x 0.125" Wall x 0.75" ID Aluminum Round Tube cut to 3.5 "
4	112.42	Arm B	1	$5.47	$10.94	Custom		1" OD x 0.125" Wall x 0.75" ID Aluminum Round Tube cut to 16"
4	112.43	Arm C	1	$8.03	$16.06	Custom		1" OD x 0.125" Wall x 0.75" ID Aluminum Round Tube cut to 23.5"
4	112.44	Shaft Collar	1	$13.94	$27.88	McMaster	60485K69	
4	112.45	Tube End Cap	1	$4.61	$9.22	McMaster	9275K142	
4	113.46	Motor Arm Plate - Right	1	$0.97	$1.94	Custom		0.125" Thick Sheet Aluminum 6061
3	112.50	Thruster Screw	4	$0.03	$0.23	Fastenal	QM2510008A20000	M3x0.5 8mm Pan Head Stainless Steel Machine Screw
3	112.60	Thruster Lock Washer	4	$0.03	$0.24	Fastenal	ML6330000A20000	M3 DIN 127 A2 Stainless Steel Split Lock Washer
3	112.70	Thruster	1	$179.00	$358.00	Blue Robotics	T200-THRUSTER-R1-RP	Blue Robotics T200 Thruster
2	114.00	Light Pole Subassembly	1	--	--	------	------	
3	114.10	Flash Head	1	--	--	LLNL	------	Not on Prototype
3	114.20	Flash Head Pole	1	$22.95	$22.95	MGS	RT-112-8G	Fiberglass Pole
3	114.30	Flash Pole Lock Pin	2	$4.68	$9.36	Fastenal	11104144	0.25"Dia x 2.5"L 18-8S/S Square Double Wire Snapper Pin
2	115.00	Battery Subassembly	1	--	--	------	------	------
3	115.10	Battery	1	$4,733.46	$4,733.46	Lithionics	74-221	12V 315 Ah Battery, Not on Prototype
3	115.20	6' Straps	2	$7.48	$14.95	NRS	60027.01.104	NRS 6' HD-Tie Down Straps
2	116.00	Payload Box Subassembly	1	--	--	------	------	------
3	116.10	Hoffman Box	1	$928.90	$928.90	Hoffman	A20H1612GQRLP	
3	116.20	Hoffman Panel	1	$42.35	$42.35	Hoffman	A20P16AL	
3	116.30	Thruster Speed Controller	4	$27.00	$108.00	Blue Robotics	BESC30-R3	Blue Robotics ESC Motor Controller
3	116.40	Payload Box Bolt	4	$1.37	$5.48	McMaster	93190A685	7/16"-20 x 1" Super Corrosion Resistant Hex Head Screw
3	116.50	Payload Box Nuts	4	$0.68	$2.72	Fastenal	37306	7/16"-20 Grade C Zinc Finish Steel Top Lock Nut
3	116.60	Through Box Connector	6	$34.05	$204.30	Mouser	MS3474L14-4P	Not on Prototype
3	116.70	Electronics Subassembly	1	--	--	------	------	------
4	116.71	Main Power Switch	1	$35.39	$35.39	Blue Sea Systems	6006200	
4	116.72	Main Power Fuse	1	$3.46	$3.46	Littelfuse Inc.	142.5631.6102	100A, 58VDC Auto Link Bold Down Fuse
4	116.73	Fuse Holder	1	$10.05	$10.05	Littelfuse Inc.	04981038HXFC	Bolt Down Fuse Holder, 32V, Chassis Mount
4	116.74	Bus Bar	2	$19.99	$39.98	Ocean River	B0107	10 Terminal, 150A Marine Bus Bar
4	116.75	Motor Cable Extension	4	$16.00	$64.00	Blue Robotics	CAB-PUR-3-16AWG-R2	2 meters each, 3 - 16AWG cable for Blue Robotics Thruster
4	116.76	ESC-Motor Cable terminal	4	$0.66	$2.64	Adels-Contact	121203	3 Connector Terminal Strip with screw connections
1	120.00	Pontoon Assembly	1	--	--	------	------	------
2	121.00	Pontoon	2	$1,044.50	$2,089.00	Maravia	------	Part ordered already
2	122.00	2' Straps	4	$5.98	$23.92	NRS	60027.01.101	NRS 2' HD-Tie Down Straps
2	123.00	3' Straps	4	$6.48	$25.90	NRS	60027.01.102	NRS 3' HD-Tie Down Straps
	Total Parts		**123**		**$9,505.97**			

M. Appendix M: Drawing Package

Assembly Level	Part Number	Description				
		Lvl0	*Lvl1*	*Lvl2*	*Lvl3*	*Lvl4*
0	100.00	Final Assembly				
1	110.00		Frame Assembly			
2	111.00			Frame Subassembly		
3	111.1A				Main Deck Length	
3	111.1B				Main Deck Width	
3	111.1C				Lower Deck Length	
3	111.1D				Lower Deck Width	
3	111.2A				Vertical Riser Bars	
3	111.2B				Upper Deck Width	
3	111.30				Flash Pole Member	
3	111.40				Main Deck Lift Member	
3	111.5A				Upper Deck Stacking Support	
3	111.5B				Lower Deck Payload Box Supports	
3	111.5C				Lower Deck Battery Supports	
3	111.60				U Bolt Mount Plate	
3	111.70				U Bolt	
3	111.80				Flash Pole Mounting Tube	
3	111.90				Flash Pole Storage Clips	
2	112.00			Motor Attachment Left		
3	112.10				Motor Mount Mounting Bolt	
3	112.20				Motor Mount Mounting Nut	
3	112.30				Motor Mount - Left	
4	112.31					Frame Mount
4	112.32					Holder Extension
4	112.33					Clip Extension
4	112.34					Top Holder
4	112.35					Bottom Holder
4	112.36					Holder Socket Screw
4	112.37					Clip Screw
4	112.38					Clip Nut
4	112.39					Clip
3	112.40				Motor Arm - Left	
4	112.41					Arm A
4	112.42					Arm B
4	112.43					Arm C
4	112.44					Shaft Collar
4	112.45					Tube End Cap
4	112.46					Motor Arm Plate - Left
3	112.50				Thruster Screw	
3	112.60				Thruster Lock Washer	
3	112.70				Thruster	
2	113.00			Motor Attachment Right		
3	112.10				Motor Mount Mounting Bolt	
3	112.20				Motor Mount Mounting Nut	
3	113.30				Motor Mount - Right	
4	112.31					Frame Mount
4	112.32					Holder Extension
4	112.33					Clip Extension
4	112.34					Top Holder

4	112.35				Bottom Holder
4	112.36				Holder Socket Screw
4	112.37				Clip Screw
4	112.38				Clip Nut
4	112.39				Clip
3	113.40			Motor Arm - Right	
4	112.41				Arm A
4	112.42				Arm B
4	112.43				Arm C
4	112.44				Shaft Collar
4	112.45				Tube End Cap
4	113.46				Motor Arm Plate - Right
3	112.50			Thruster Screw	
3	112.60			Thruster Lock Washer	
3	112.70			Thruster	
2	114.00		Light Pole Subassembly		
3	114.10			Flash Head	
3	114.20			Flash Head Pole	
3	114.30			Flash Pole Lock Pin	
2	115.00		Battery Subassembly		
3	115.10			Battery	
3	115.20			6' Straps	
2	116.00		Payload Box Subassembly		
3	116.10			Hoffman Box	
3	116.20			Hoffman Panel	
3	116.30			Thruster Speed Controller	
3	116.40			Payload Box Bolt	
3	116.50			Payload Box Nuts	
3	116.60			Through Box Connector	
3	116.70			Electronics Subassembly	
4	116.71				Main Power Switch
4	116.72				Main Power Fuse
4	116.73				Fuse Holder
4	116.74				Bus Bar
4	116.75				Motor Cable Extension
4	116.76				ESC-Motor Cable terminal
1	120.00	Pontoon Assembly			
2	121.00		Pontoon		
2	122.00		2' Straps		
2	123.00		3' Straps		





DETAIL A
SCALE 1 : 12

UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

Final Assembly

CAL POLY SENIOR PROJECT

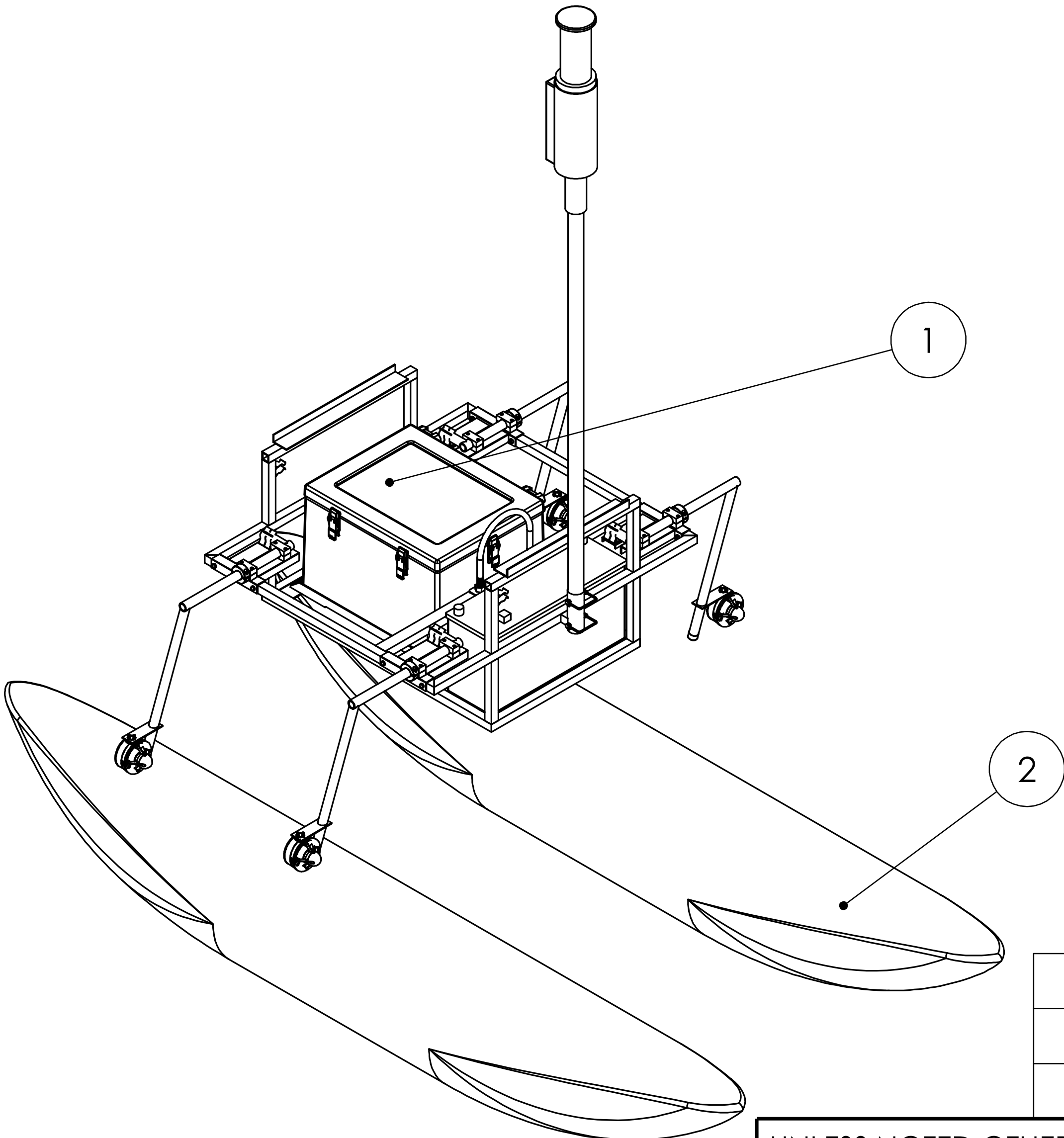
Research Raft

SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	J. DAVIS	02/24/21
CHECKED:	J. DAVIS	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.:	100.00	PRT. NO.:	100.00
NXT. ASB.:	--	SCALE: 1:20	SHEET 1 OF 2

NOTES
PONTOONS ATTACH TO FRAME WITH 2' AND 3' NRS STRAPS, PRT. NO. 122.00 AND 123.00



ITEM NO.	PART NAME	PART NO.	QTY.
2	Pontoon Assembly	120.00	1
1	Frame Assembly	110.00	1

UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

Final Assembly

CAL POLY SENIOR PROJECT

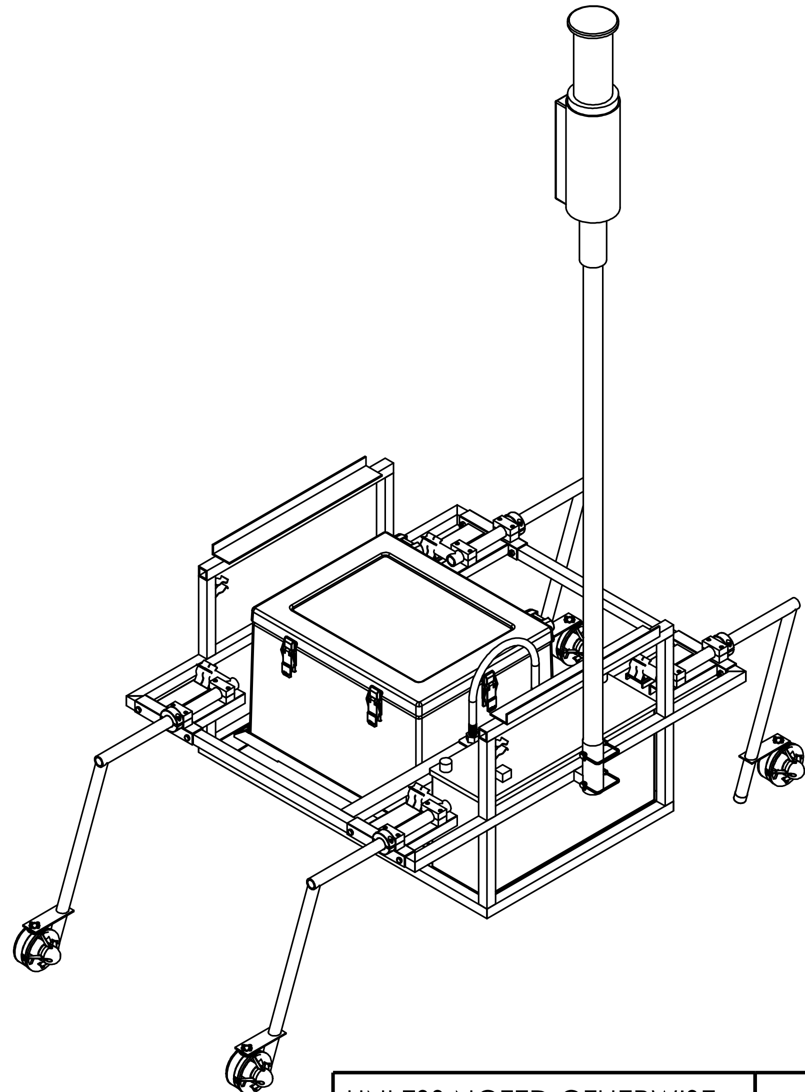
Research Raft

SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	J. DAVIS	02/24/21
CHECKED:	J. DAVIS	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 100.00 - E | PRT. NO.: 100.00

NXT. ASB.: -- | SCALE: 1:20 | SHEET 2 OF 2



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

Frame Assembly

CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	J. DAVIS	02/24/21
CHECKED:	J. DAVIS	06/07/21
APPROVED:	A. FLEMING	06/07/21

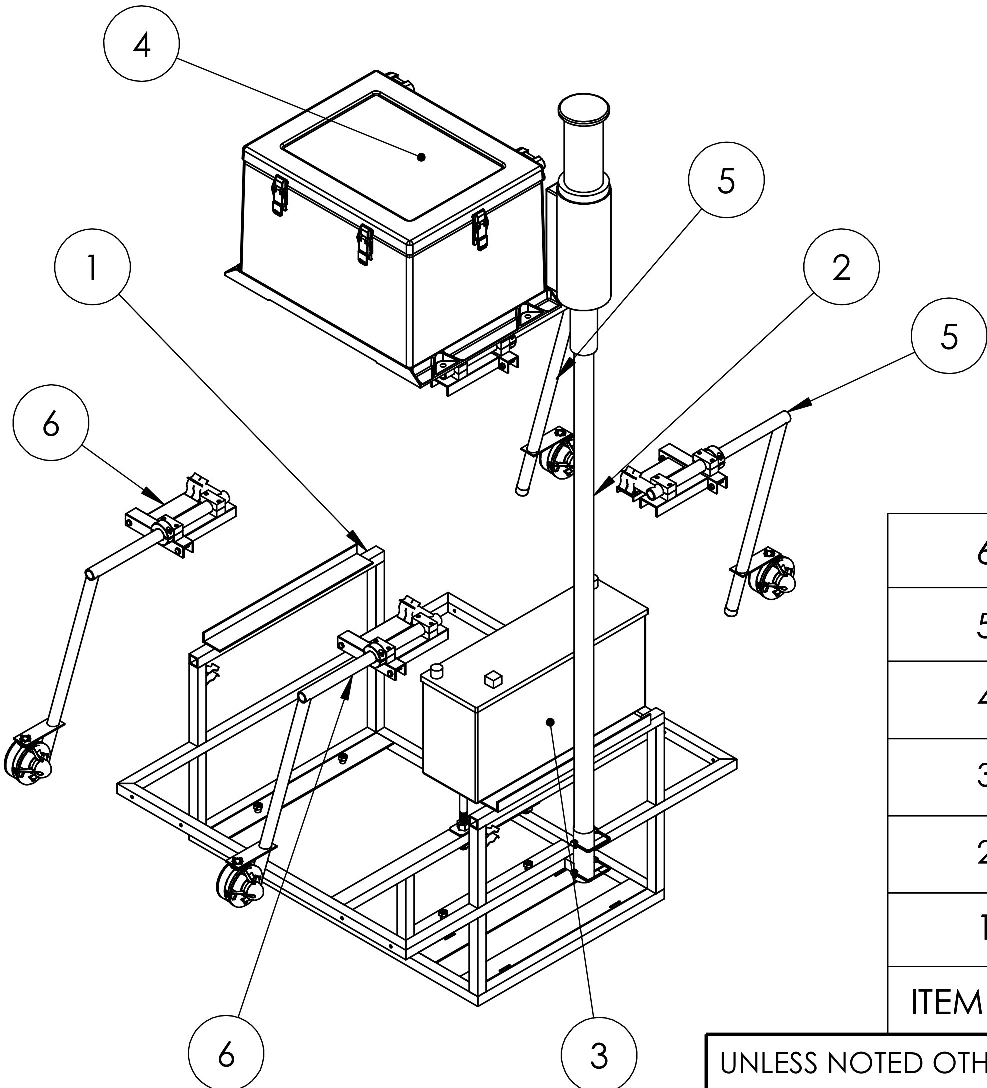
DWG. NO.: 110.00	PRT. NO.: 110.00	
NXT. ASB.: 100.00	SCALE: 1:16	SHEET 1 OF 2

NOTES:

MOTOR ATTACHMENT LEFT AND MOTOR ATTACHMENT RIGHT ARE MIRRORED VERSIONS OF THE SAME ASSEMBLY, WITH PART MODIFICATIONS AS NEEDED.

PARTS COLLAPSE VERTICALLY

FASTENERS ARE WITHIN THE CORRESPONDING SUBASSEMBLY



ITEM NO.	PART NAME	PART NO.	QTY.
6	Motor Attachment - R	113.00	2
5	Motor Attachment - L	112.00	2
4	Payload Box Subassembly	115.00	1
3	Battery Subassembly	114.00	1
2	Light Pole Subassembly	113.00	1
1	Frame Subassembly	111.00	1

UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

Frame Assembly

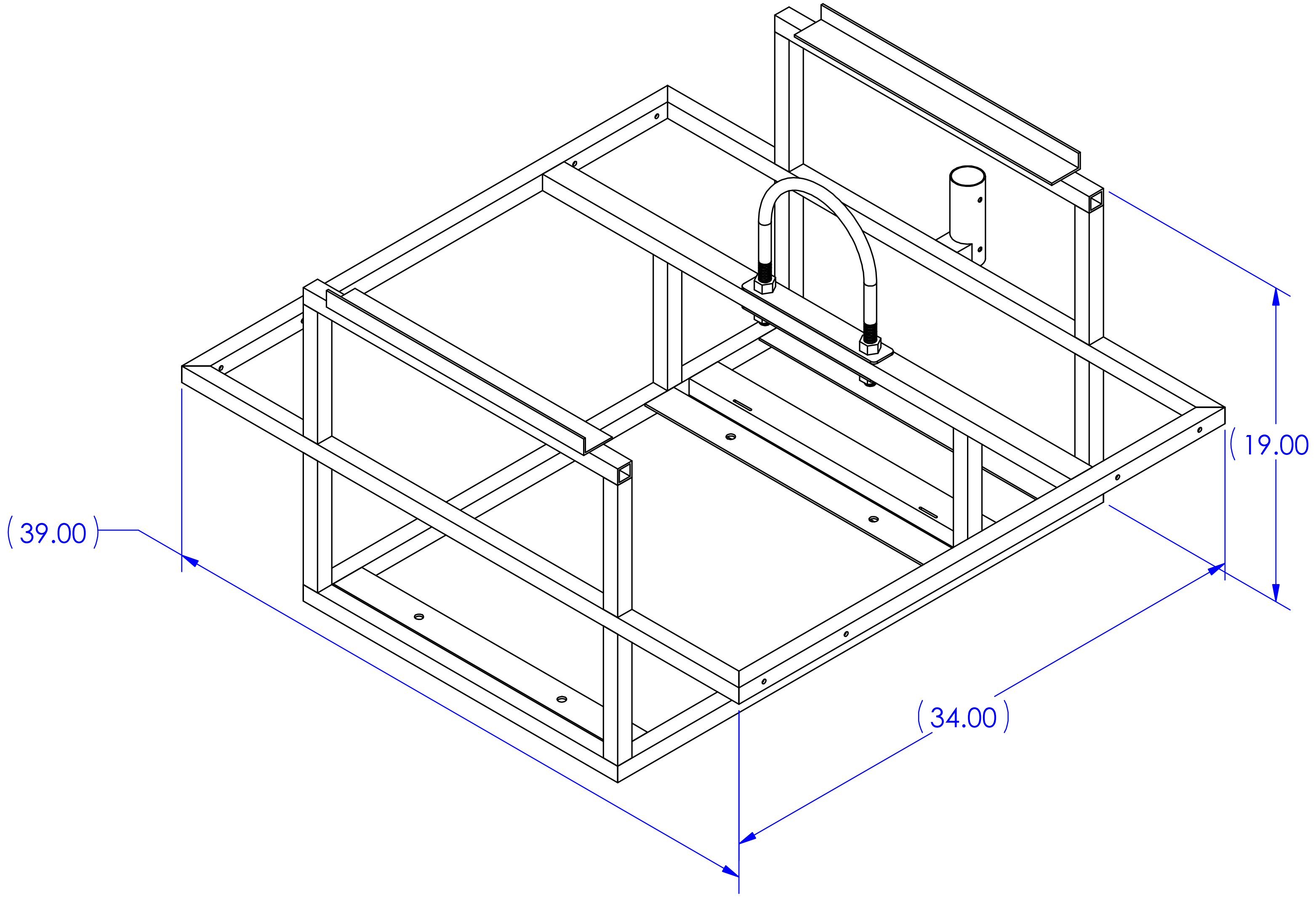
CAL POLY SENIOR PROJECT

Research Raft

SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	J. DAVIS	02/24/21
CHECKED:	J. DAVIS	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 110.00 - E	PRT. NO.: 110.00	
NXT. ASB.: 100.00	SCALE: 1:16	SHEET 2 OF 2



UNLESS NOTED OTHERWISE: ALL DIMS IN INCHES X.XX ± .02 X.XXX ± .005	TITLE: Frame Subassembly

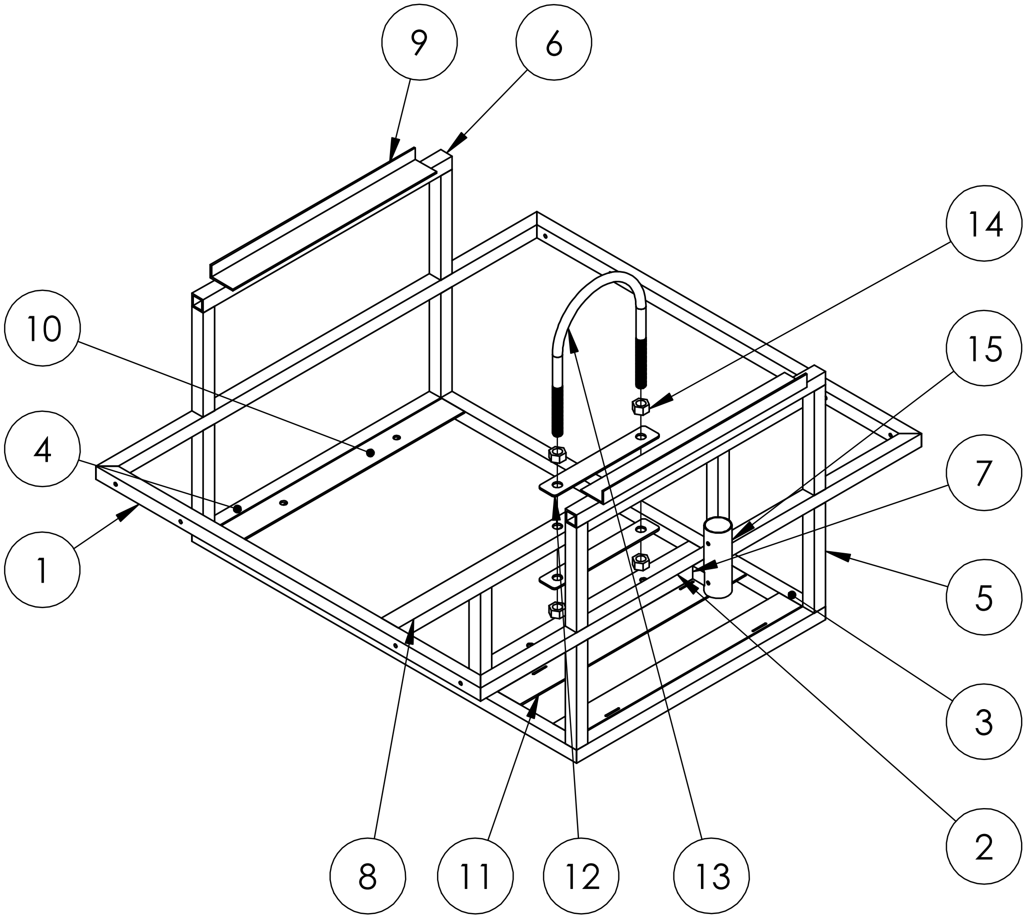
CAL POLY SENIOR PROJECT

Research Raft

SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	J. DAVIS	02/11/21
CHECKED:	J. DAVIS	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 111.00		PRT. NO.: 111.00	
NXT. ASB.: 110.00	SCALE: 1:8	SHEET 1 OF 6	



NOTES
PARTS 1-11 & 15 ARE WELDED. SEE DWG 111.00-W

ITEM NO.	PART NAME	PART NO.	QTY.
15	Flash Pole Mounting Tube	111.80	1
14	5/8-11 316 Stainless Steel Nuts	111.70	4
13	316 Stainless Steel U-Bolt	111.70	1
12	U-Bolt Mount Plate	111.60	2
11	Lower Deck Battery Supports	111.5C	2
10	Lower Deck Payload Supports	111.5B	2
9	Upper Deck Stacking Support	111.5A	2
8	Main Deck Lift Member	111.40	1
7	Flash Pole Member	111.30	1
6	Upper Deck Width	111.2B	2
5	Vertical Riser Bars	111.2A	10
4	Lower Deck Width	111.1D	2
3	Lower Deck Length	111.1C	2
2	Main Deck Width	111.1B	2
1	Main Deck Length	111.1A	2

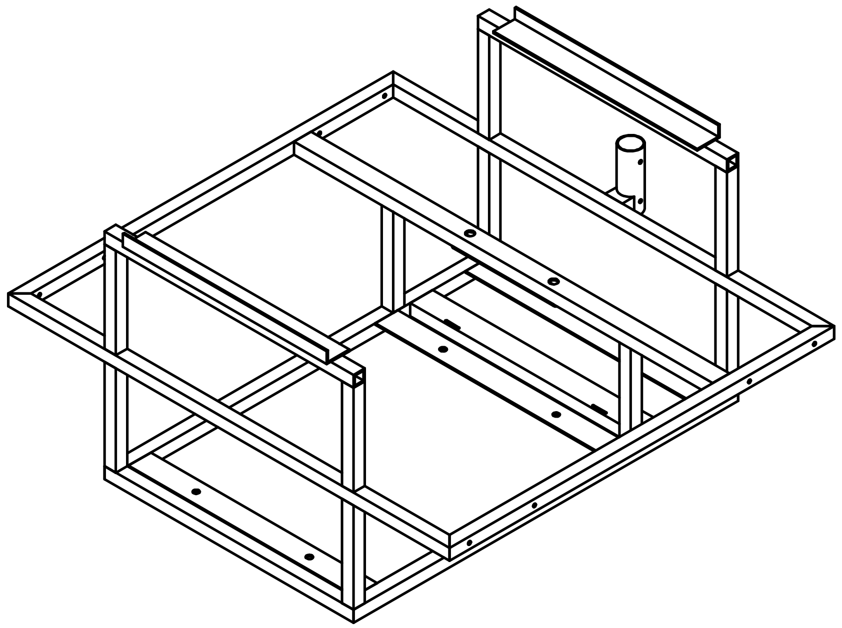
UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:
Frame Subassembly

CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

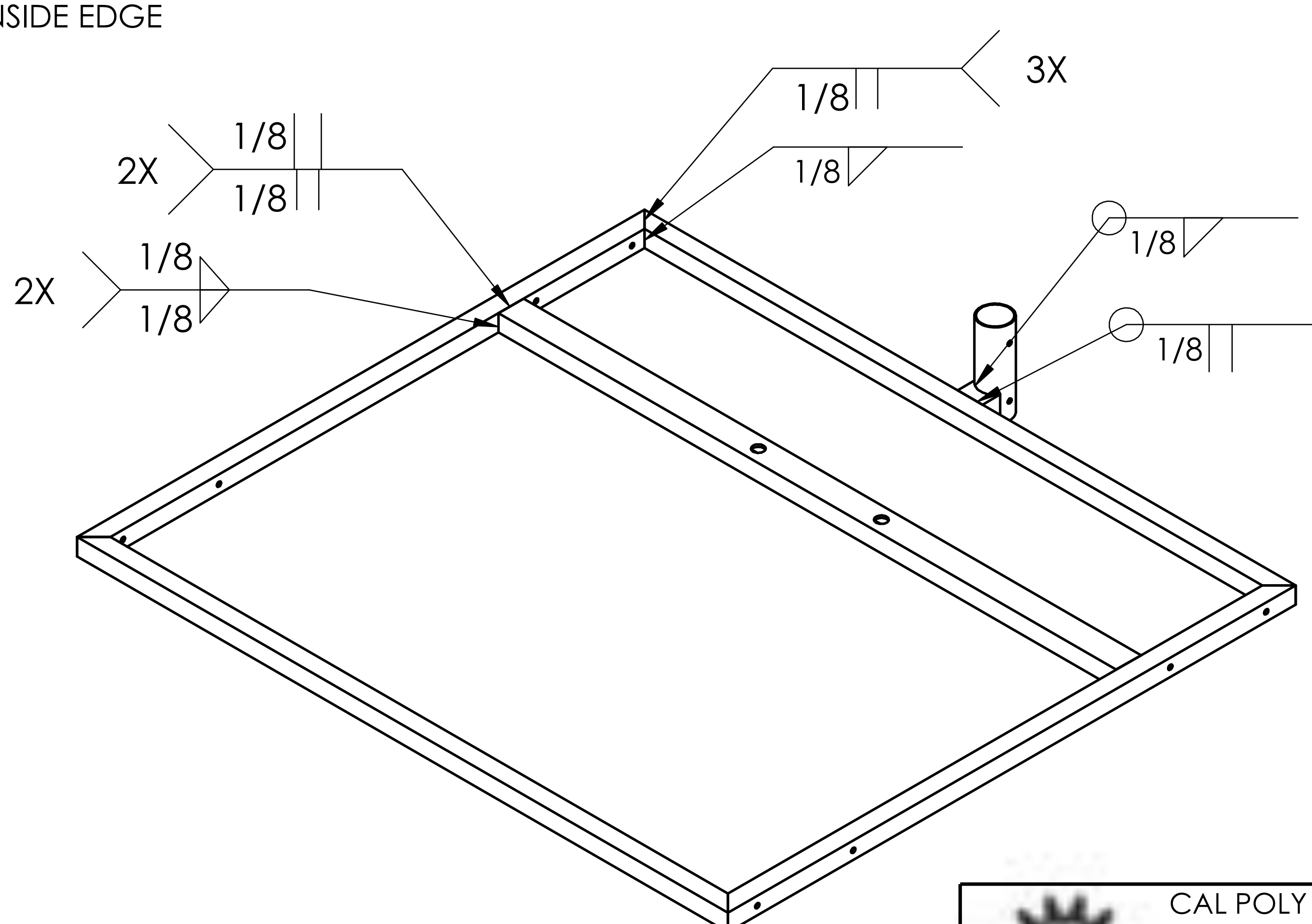
	NAME	DATE
DRAWN:	J. DAVIS	02/10/21
CHECKED:	J. DAVIS	06/07/21
APPROVED:	A. FLEMING	06/07/21

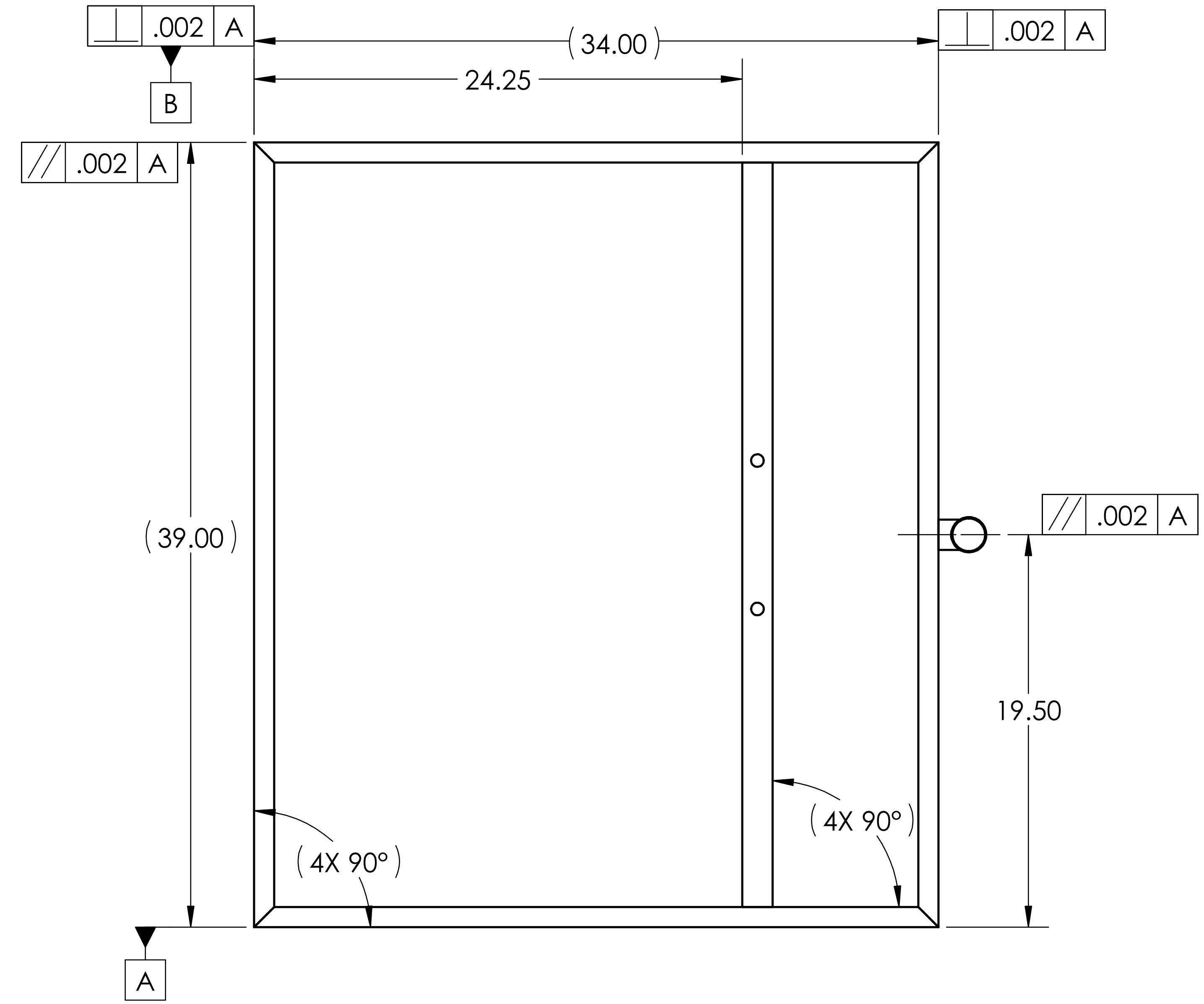
DWG. NO.: 111.00 - E	PRT. NO.: 111.00	
NXT. ASB.: 110.00	SCALE: 1:12	SHEET 2 OF 6

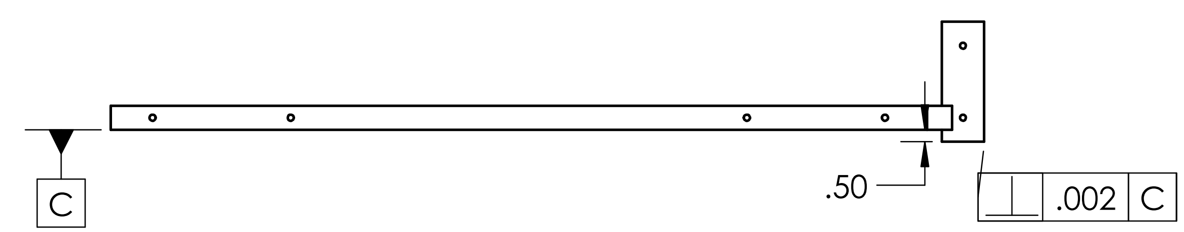


SCALE 1:12

NOTES
5356 ALUMINUM FILLER ROD
3X SQUARE GROOVE AND 1/8 FILLET REPEATED AT EACH OUTSIDE CORNER, WITH FILLETS ON INSIDE EDGE



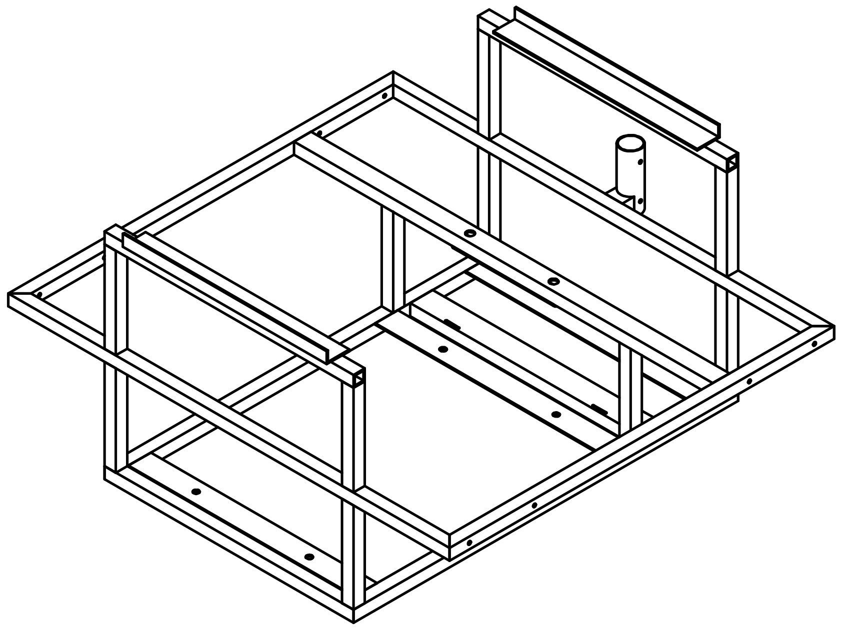




UNLESS NOTED OTHERWISE: ALL DIMS IN INCHES X.XX ± .02 X.XXX ± .005	TITLE: Frame Subassembly	

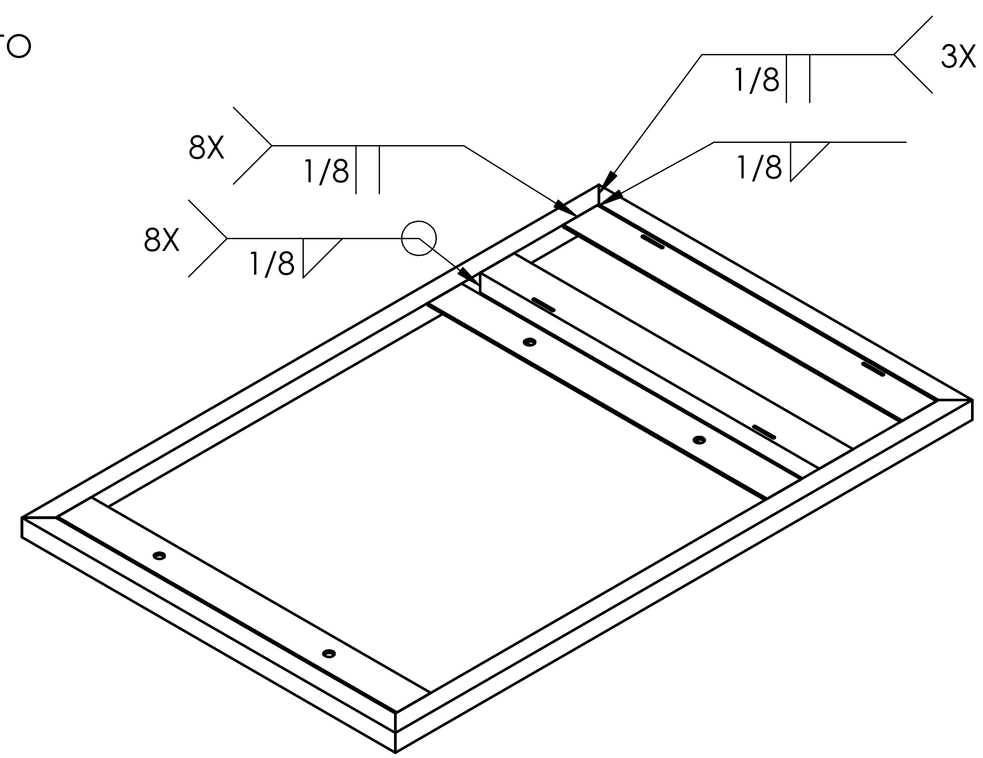
CAL POLY SENIOR PROJECT Research Raft SEPT 2020 - JUNE 2021		NAME	DATE
	DRAWN:	J. DAVIS	02/11/21
	CHECKED:	J. DAVIS	06/07/21
	APPROVED:	A. FLEMING	06/07/21

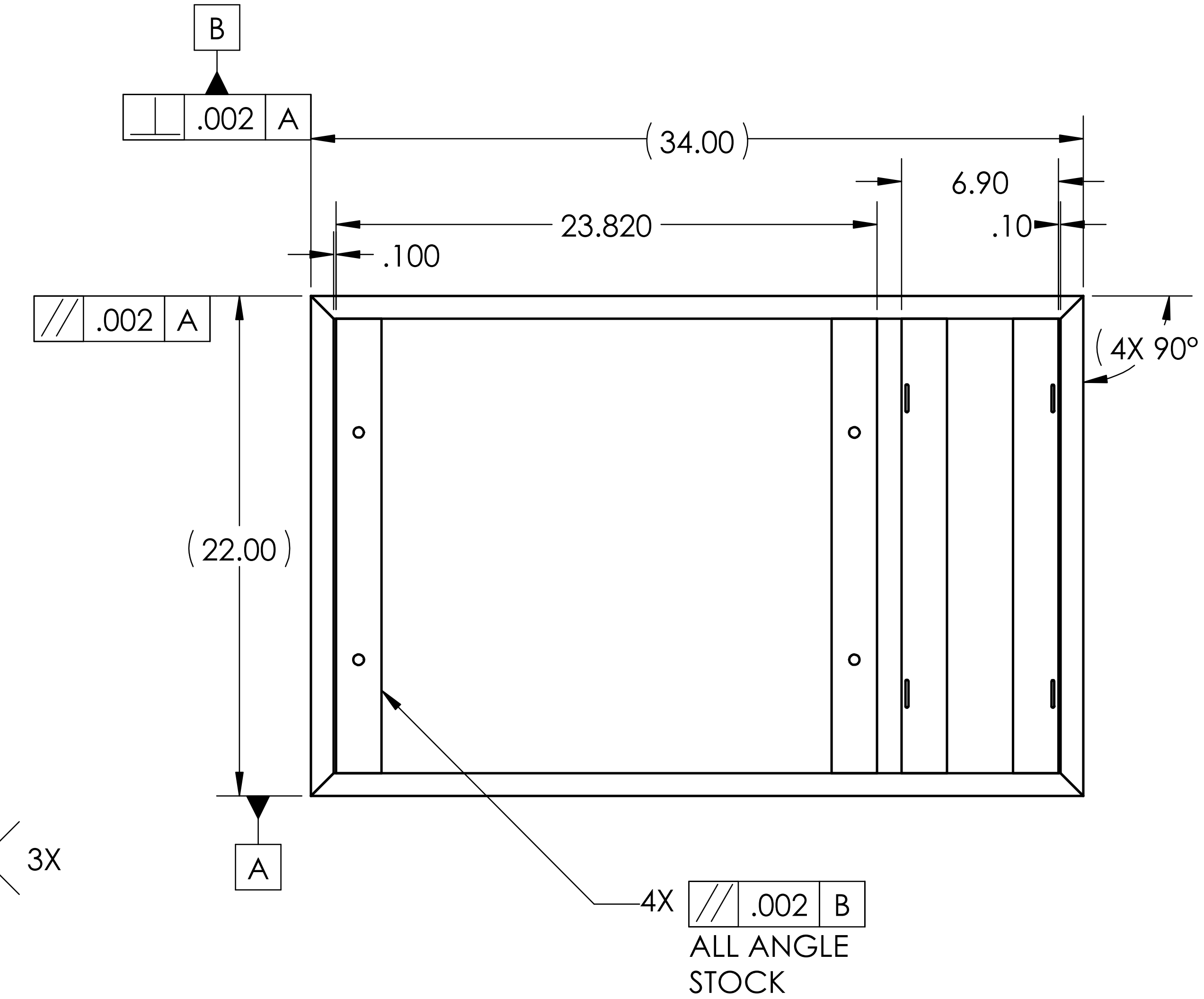
DWG. NO.: 111.00 - W1	PRT. NO.: 111.00	
NXT. ASB.: 110.00	SCALE: 1:8	SHEET 3 OF 6



SCALE 1:12

NOTES
- 5356 ALUMINUM FILLER ROD
- 3X SQUARE GROOVE AND 1/8 FILLET REPEATED AT EACH OUTSIDE CORNER, WITH FILLETS ON INSIDE EDGE
- ALL AROUND FILLET WELD DOES NOT APPLY TO 8X SQUARE GROOVE WELD
- WHERE WELD SIZE IS GREATER THAN SPACE ALLOWS, NO WELD NEED BE ADDED





UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

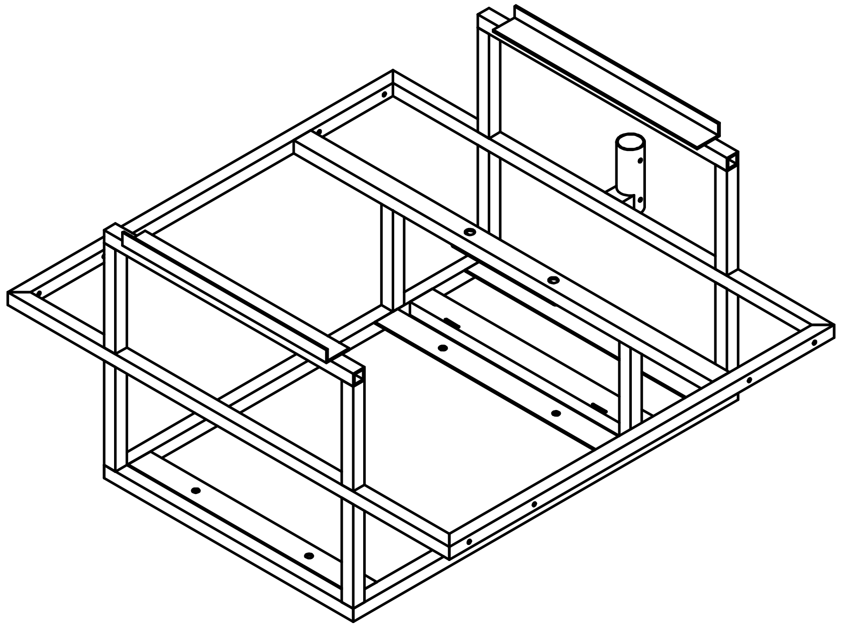
TITLE:

Frame Subassembly

CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

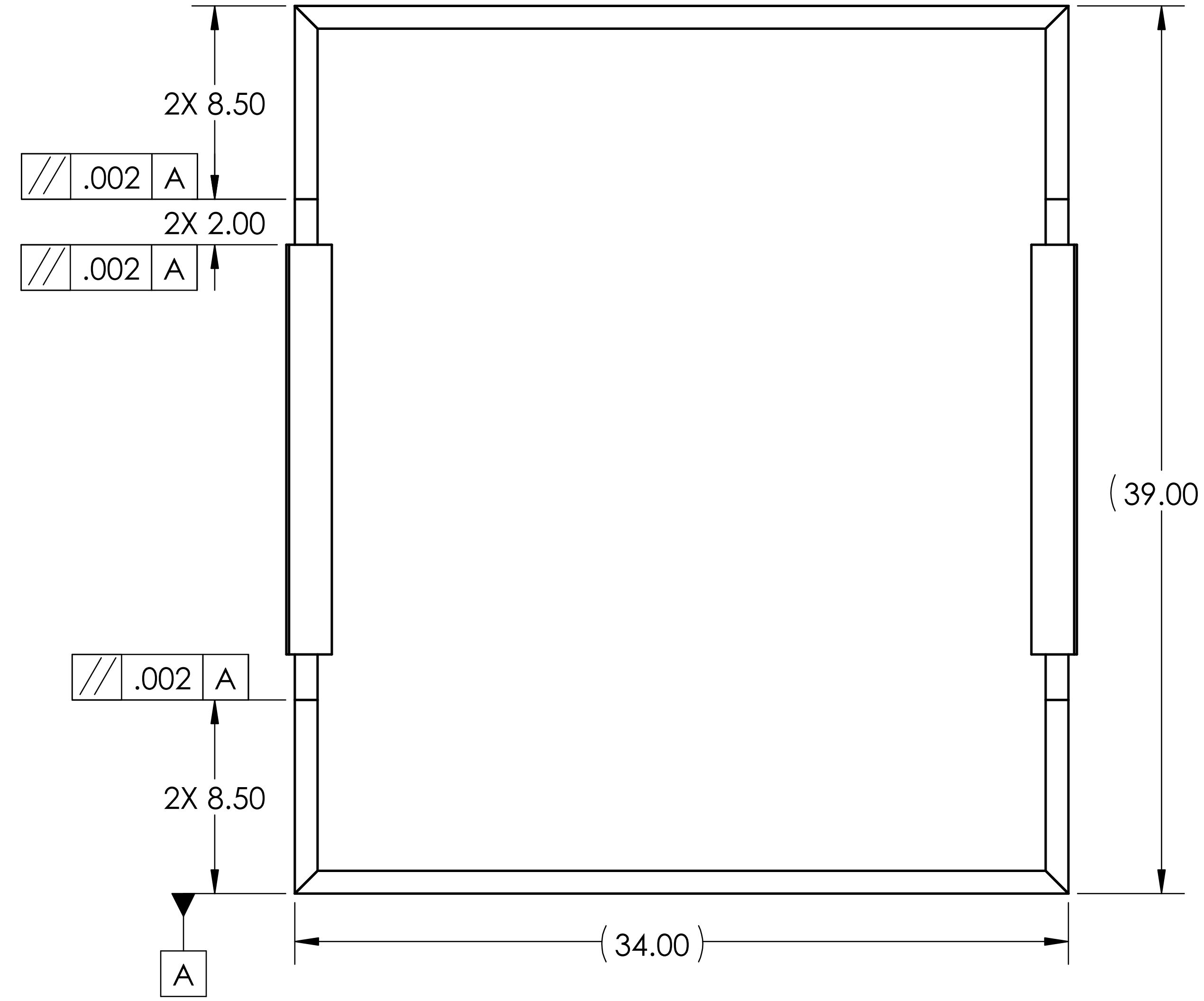
	NAME	DATE
DRAWN:	J. DAVIS	02/24/21
CHECKED:	J. DAVIS	06/07/21
APPROVED:	A. FLEMING	06/07/21

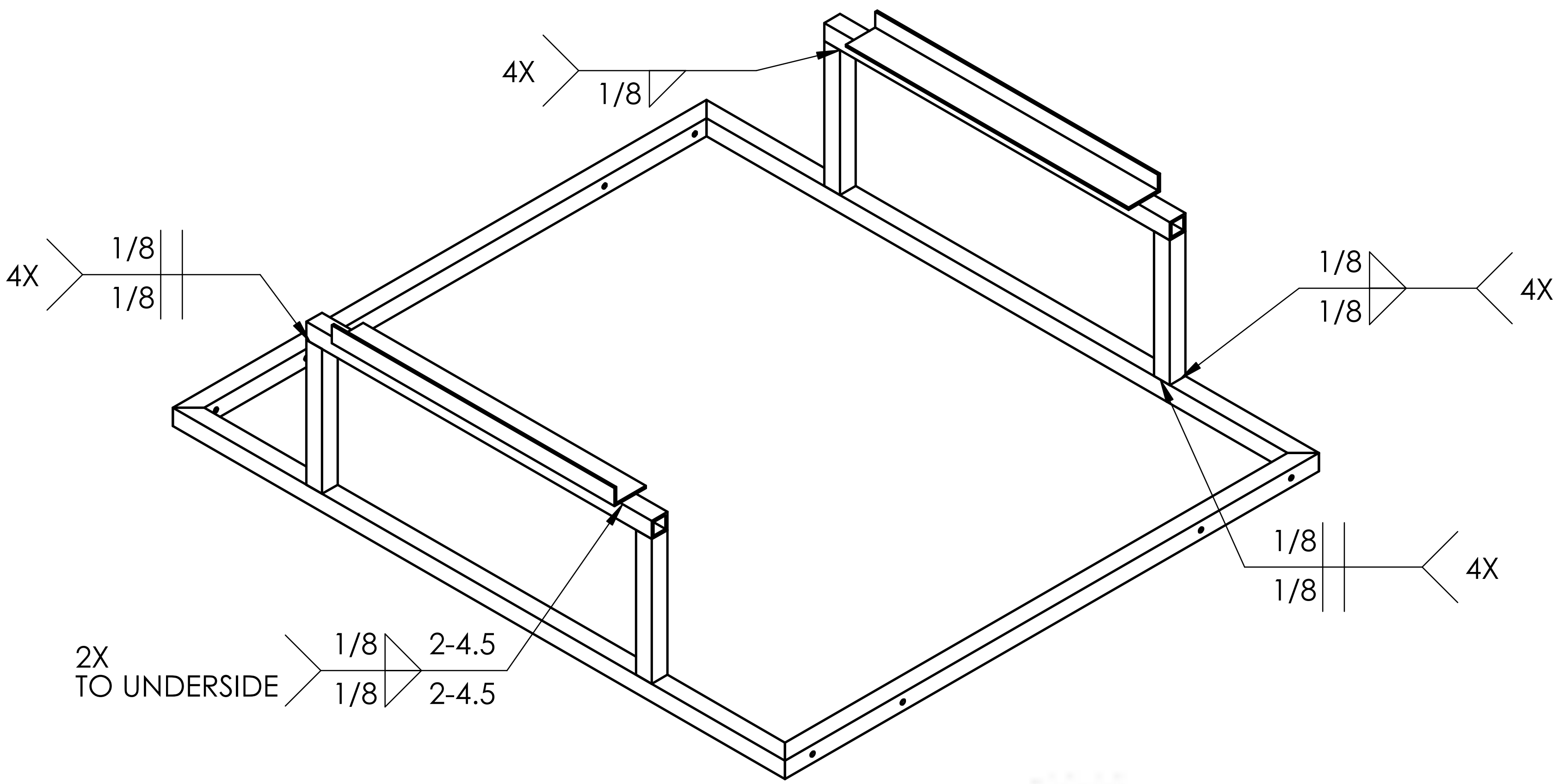
DWG. NO.: 111.00 - W2	PRT. NO.: 111.00	
NXT. ASB.: 110.00	SCALE: 1:8	SHEET 4 OF 6



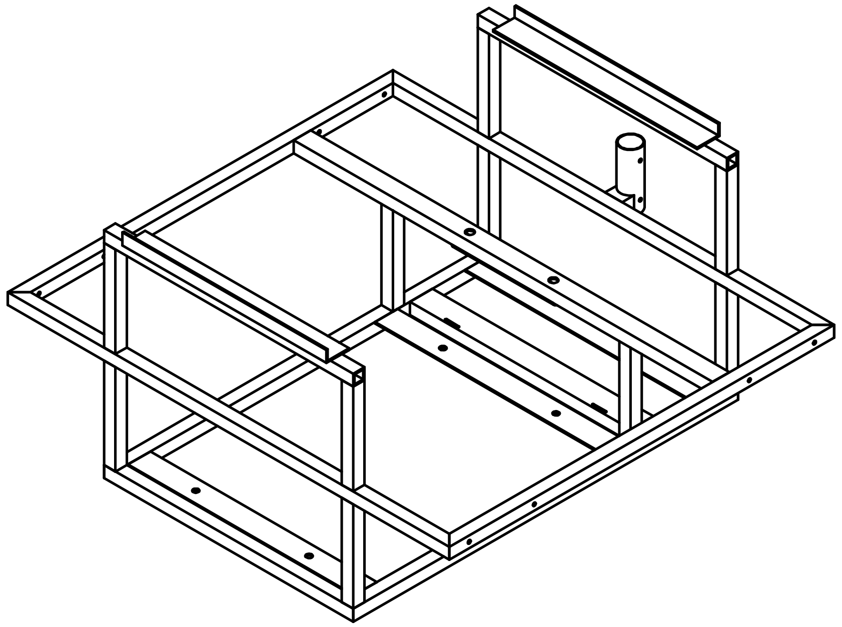
SCALE 1:12

NOTES
5356 ALUMINUM FILLER ROD
INCREMENT WELD ON UNDERSIDE OF ANGLE STOCK
ALL MEMBERS FORM 90° ANGLES AT JOINTS



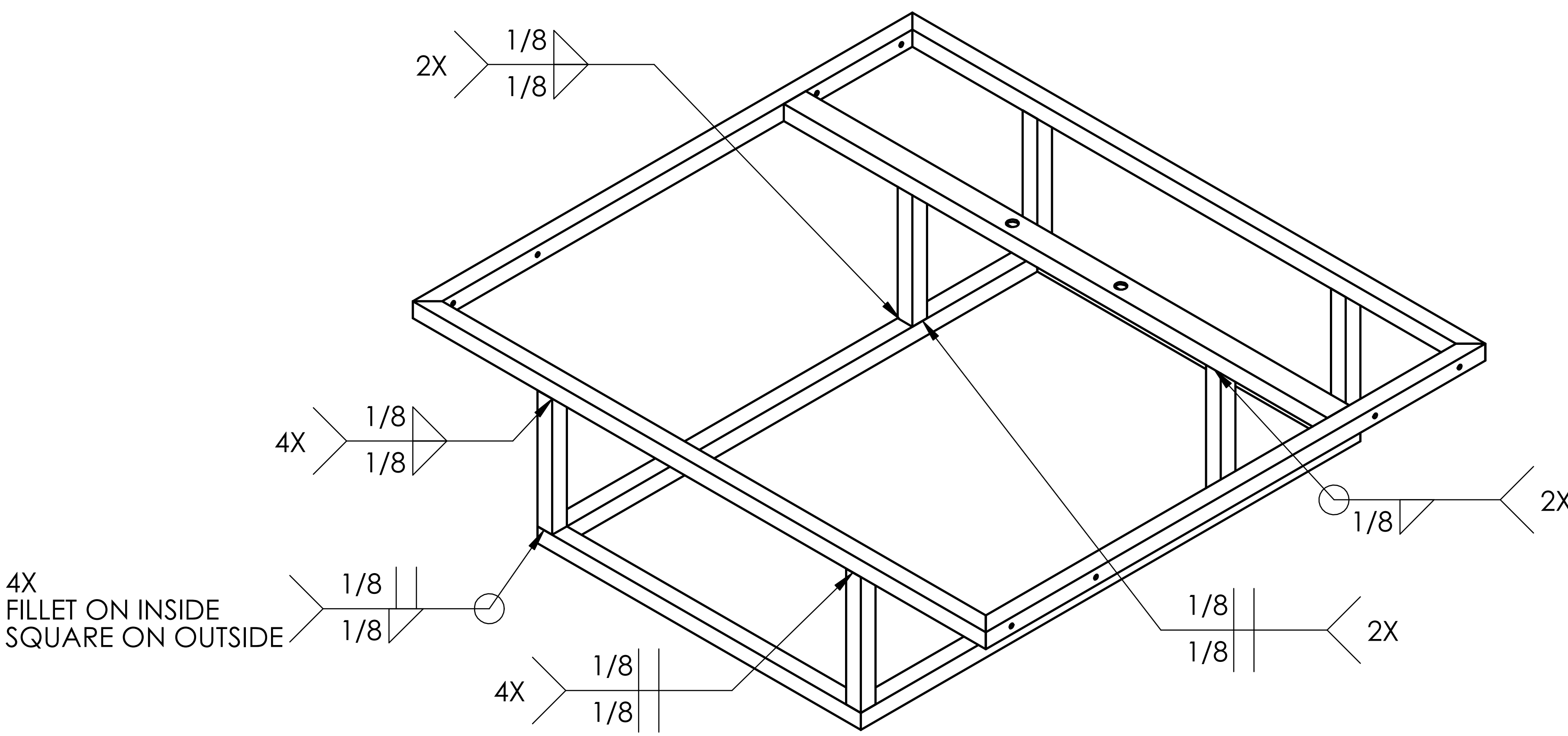


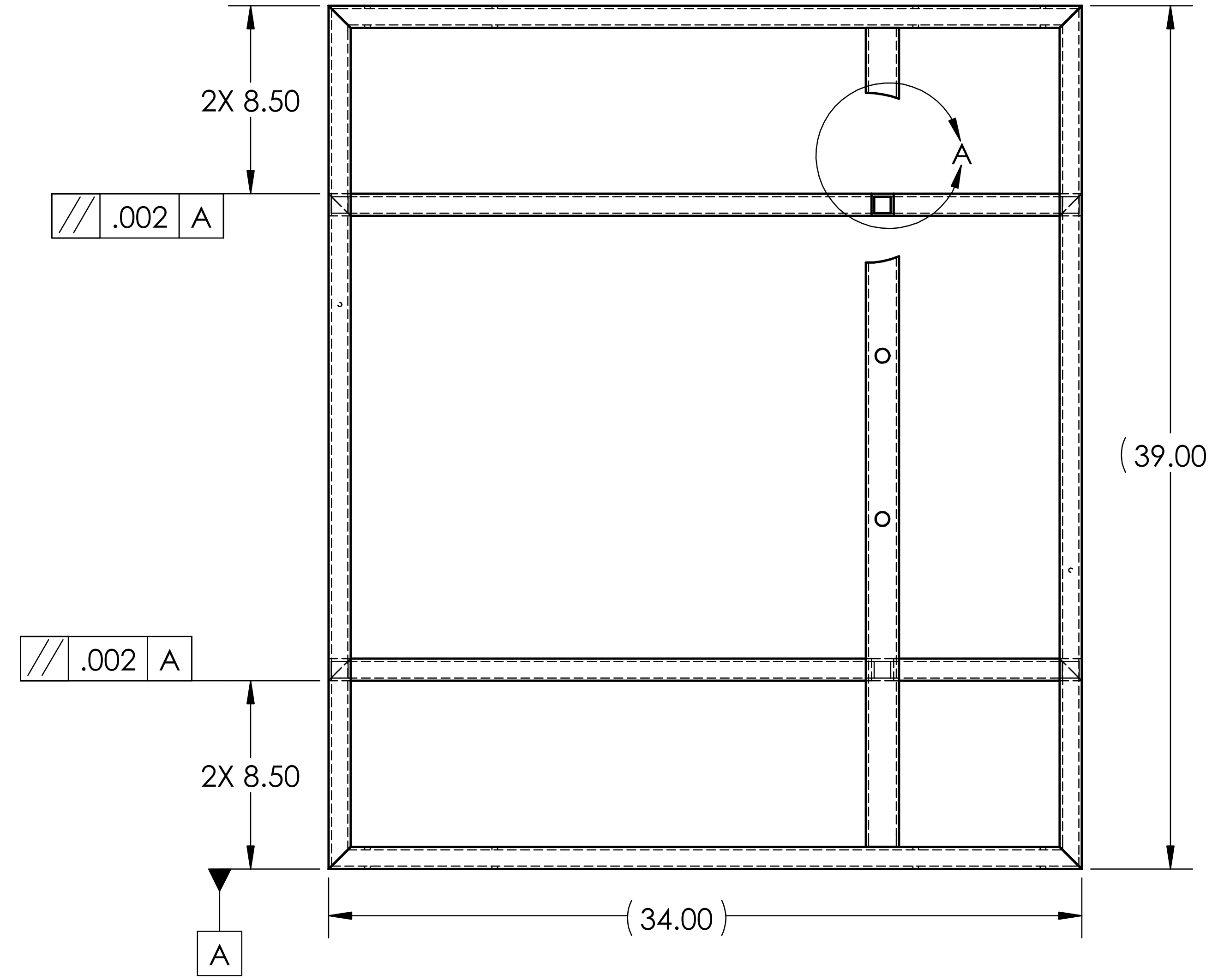
UNLESS NOTED OTHERWISE: ALL DIMS IN INCHES X.XX ± .02 X.XXX ± .005		TITLE: Frame Subassembly	
CAL POLY SENIOR PROJECT	NAME	DATE	
Research Raft	DRAWN: J. DAVIS	02/24/21	DWG. NO.: 111.00 - W3 / PRT. NO.: 111.00
SEPT 2020 - JUNE 2021	CHECKED: J. DAVIS	06/07/21	NXT. ASB.: 110.00 / SCALE: 1:8 / SHEET 5 OF 6
	APPROVED: A. FLEMING	06/07/21	

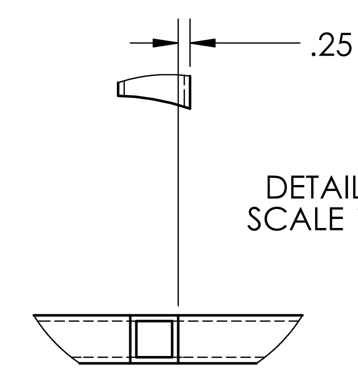


SCALE 1:12

NOTES
5356 ALUMINUM FILLER ROD
ALL MEMBERS FORM 90° ANGLES AT JOINTS







DETAIL A
SCALE 1 : 4

UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

Frame Subassembly

CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

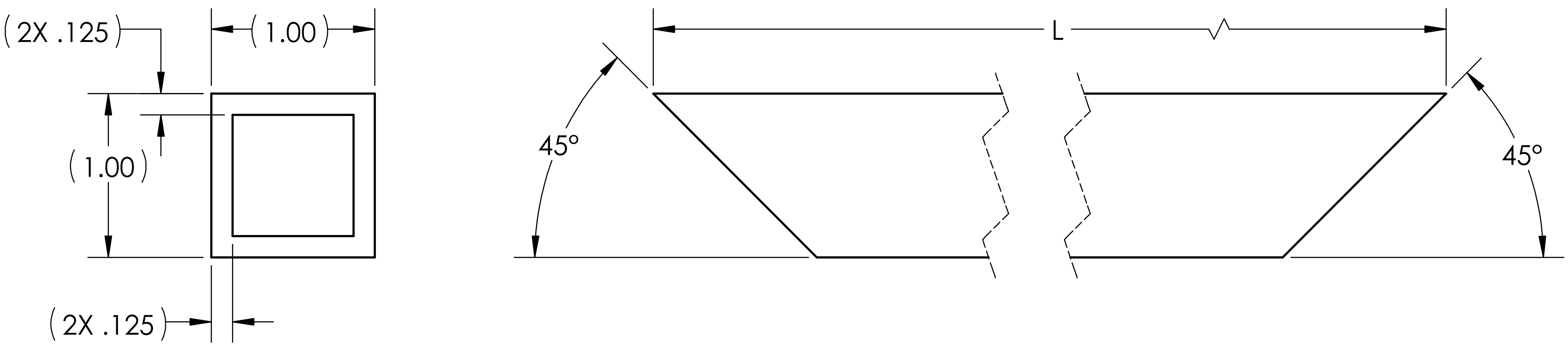
	NAME	DATE
DRAWN:	J. DAVIS	02/24/21
CHECKED:	J. DAVIS	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 111.00 - W4		PRT. NO.: 111.00	
NXT. ASB.: 110.00	SCALE: 1:8	SHEET 6 OF 6	

NOTES:
USE AL. 6061-T6 1.0 IN SQUARE TUBE STOCK
1/8TH INCH WALL THICKNESS

CUT TO LENGTH FROM CUT LIST
ANGLE ENDS ±1°
BREAK SHARP EDGES .01 MAX

PART #	DESCRIPTION	QTY.	LENGTH (L)
111.1A	MAIN DECK LENGTH	2	34.00
111.1B	MAIN DECK WIDTH	2	39.00
111.1C	LOWER DECK LENGTH	2	34.00
111.1D	LOWER DECK WIDTH	2	22.00



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

FRAME MEMBERS - ANGLED

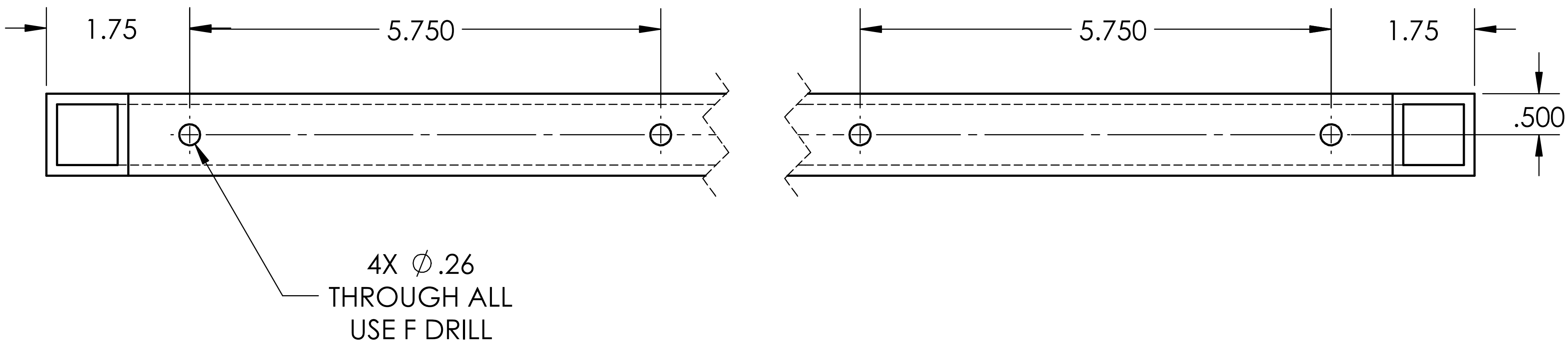
CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	A. FLEMING	02/23/21
CHECKED:	A. FLEMING	06/06/21
APPROVED:	J. DAVIS	06/07/21

DWG. NO.: 111.10 PRT. NO.: 111.10

NXT. ASB.: 111.00 SCALE: 1:1 SHEET 1 OF 1

NOTES:
FROM DWG. NO. 111.10 CUT LIST
BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

MAIN DECK LENGTH

CAL POLY SENIOR PROJECT

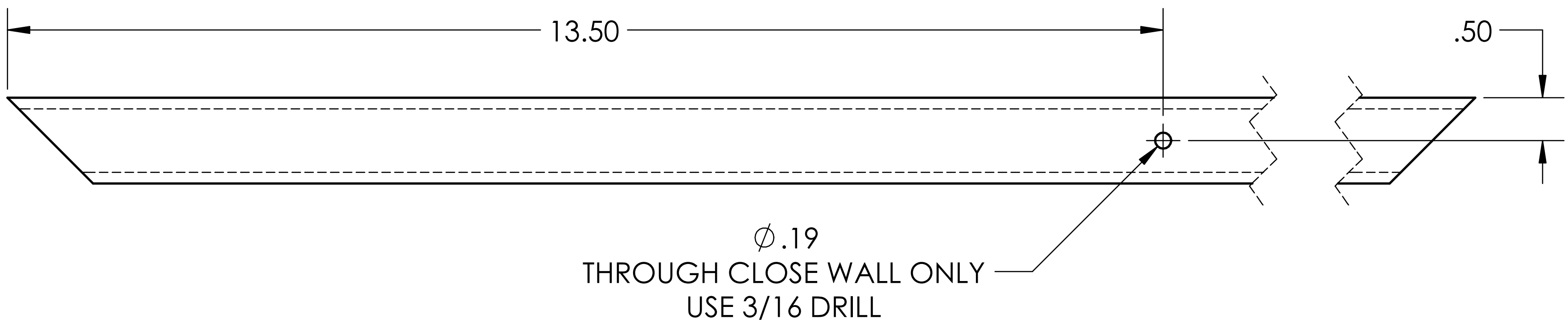
Research Raft

SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	A. FLEMING	02/24/21
CHECKED:	A. FLEMING	06/06/21
APPROVED:	J. DAVIS	06/07/21

DWG. NO.: 111.1A	PRT. NO.: 111.1A	
NXT. ASB.: 111.00	SCALE: 1:2	SHEET 1 OF 1

NOTES:
FROM DWG. NO. 111.1B CUT LIST
BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

MAIN DECK WIDTH

CAL POLY SENIOR PROJECT

Research Raft

SEPT 2020 - JUNE 2021

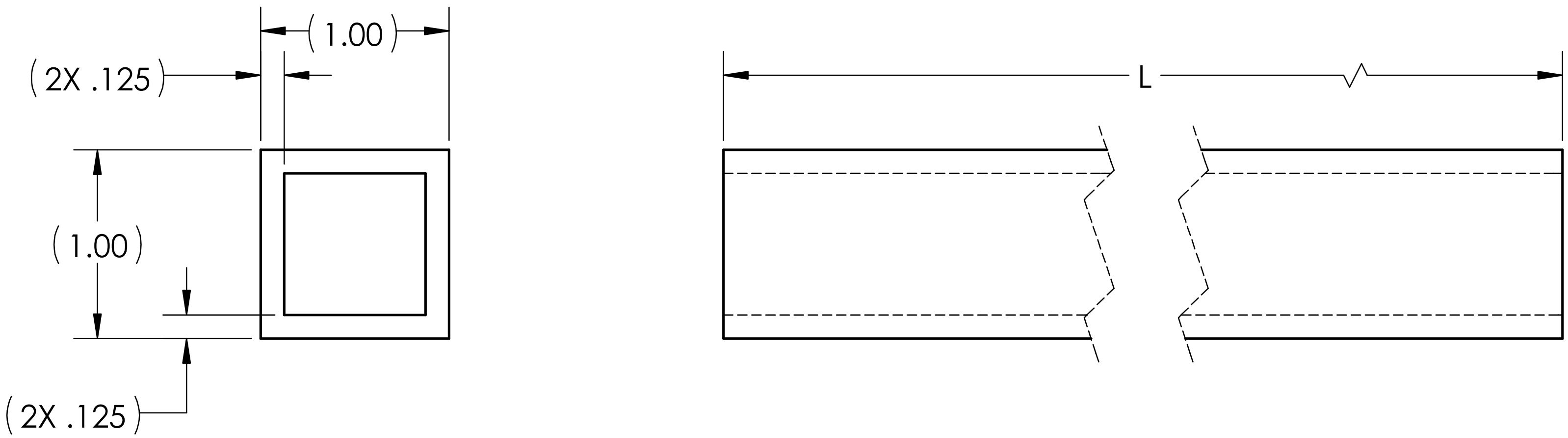
	NAME	DATE
DRAWN:	A. FLEMING	02/24/21
CHECKED:	A. FLEMING	06/06/21
APPROVED:	J. DAVIS	06/07/21

DWG. NO.:	111.1B	PRT. NO.:	111.1B
NXT. ASB.: 111.00	SCALE: 1:2	SHEET 1 OF 1	

NOTES:
USE AL. 6061-T6 1.0 INCH SQUARE TUBE
1/8 INCH WALL THICKNESS

CUT TO LENGTH FROM CUT LIST
BREAK SHARP EDGES .01 MAX

PART #	DESCRIPTION	QTY.	LENGTH (L)
111.2A	VERTICAL RISER BAR	10	8.00
111.2B	UPPER DECK WIDTH	2	22.00



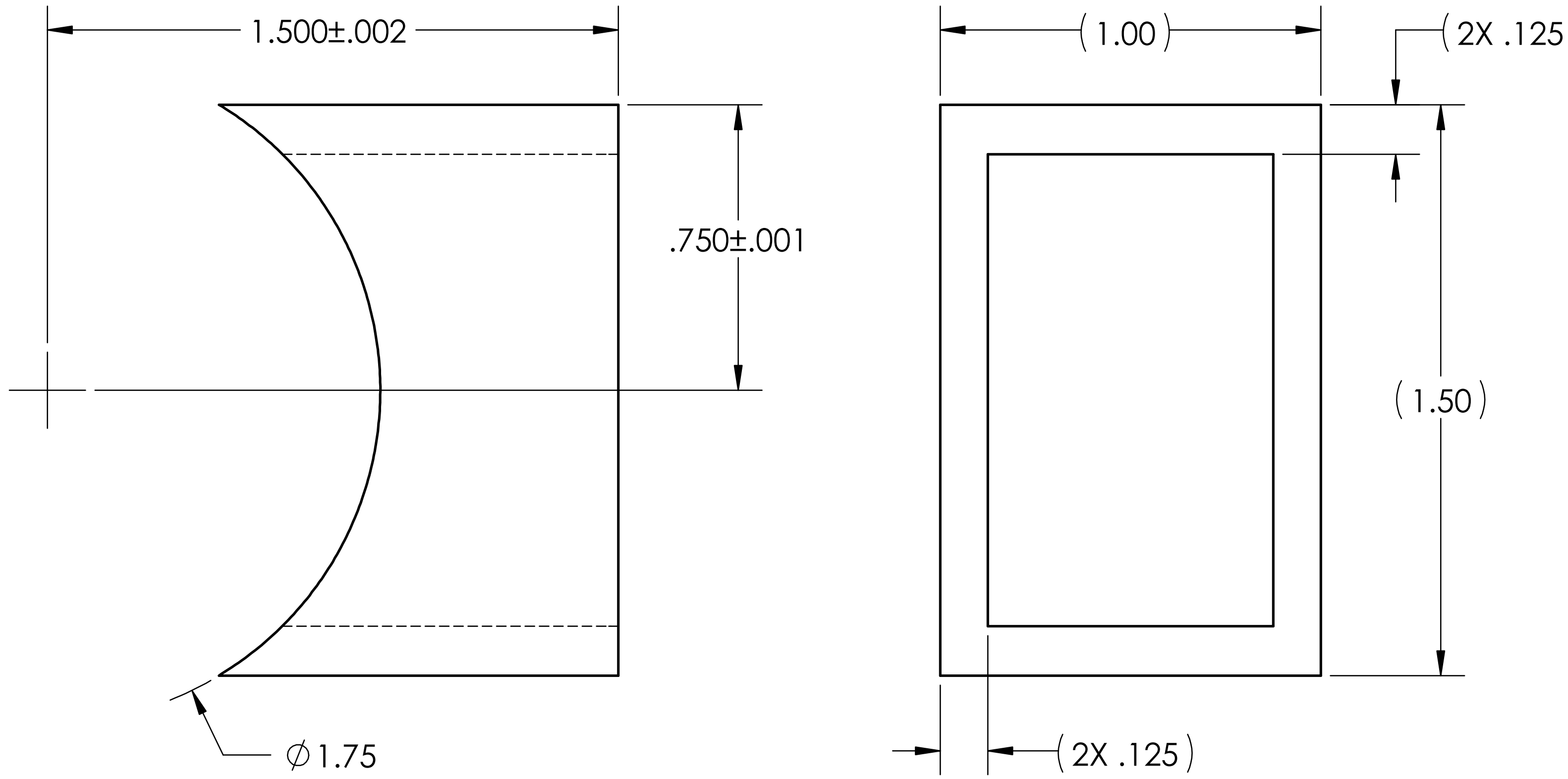
UNLESS NOTED OTHERWISE: ALL DIMS IN INCHES X.XX ± .02 X.XXX ± .005	TITLE: FRAME MEMBERS - FLAT	

CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	A. FLEMING	02/18/21
CHECKED:	A. FLEMING	06/06/21
APPROVED:	J. DAVIS	06/07/21

DWG. NO.: 111.20	PRT. NO.: 111.20	
NXT. ASB.: 111.00	SCALE: 1:1	SHEET 1 OF 1

NOTES:
USE AL. 6061-T6 1IN X 1.5IN TUBE
1/8 INCH WALL THICKNESS
BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

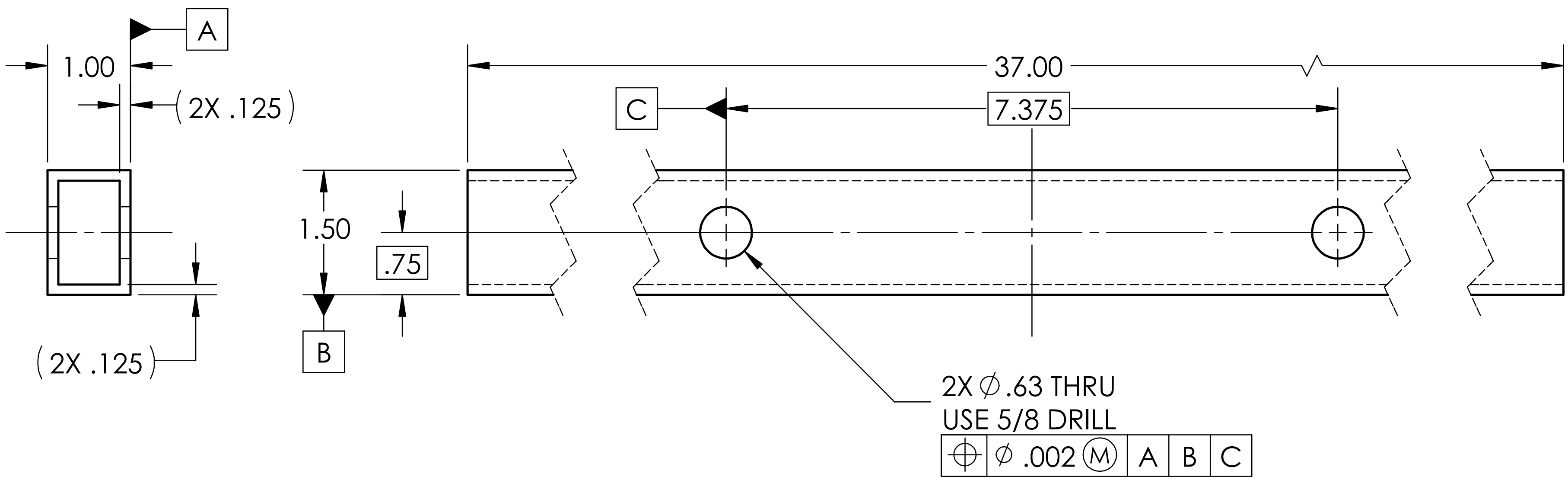
FLASH POLE MEMBER

CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	A. FLEMING	02/23/21
CHECKED:	A. FLEMING	06/06/21
APPROVED:	J. DAVIS	06/07/21

DWG. NO.: 111.30		PRT. NO.: 111.30	
NXT. ASB.: 111.00	SCALE: 2:1	SHEET 1 OF 1	

NOTES:
USE AL. 6061-T6 RECTANGULAR TUBE
1/8 INCH WALL THICKNESS
BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

MAIN DECK LIFT MEMBER

CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

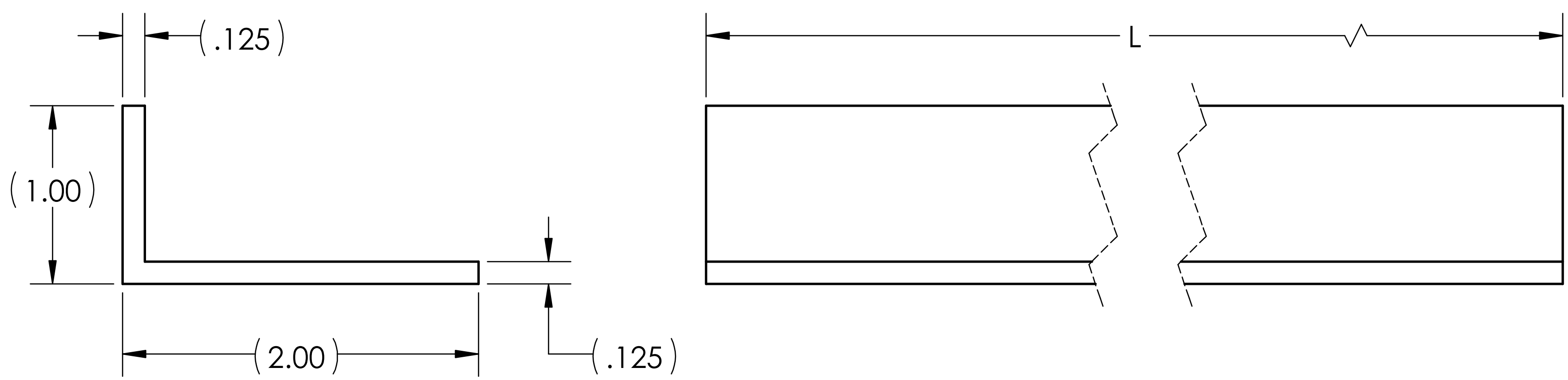
	NAME	DATE
DRAWN:	A. FLEMING	02/18/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	J. DAVIS	06/07/21

DWG. NO.: 111.40		PRT. NO.: 111.40	
NXT. ASB.: 111.00	SCALE: 1:2	SHEET 1 OF 1	

NOTES:
USE AL. 6061-T6 1 X 2 INCH ANGLE STOCK
1/8TH INCH WALL THICKNESS

CUT TO LENGTH FROM CUT LIST
BREAK SHARP EDGES .01 MAX

PART #	DESCRIPTION	QTY.	LENGTH (L)
111.5A	UPPER DECK STACKING SUPPORT	2	18.00
111.5B	LOWER DECK PAYLOAD BOX SUPPORT	2	20.00
111.5C	LOWER DECK BATTERY SUPPORT	2	20.00



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

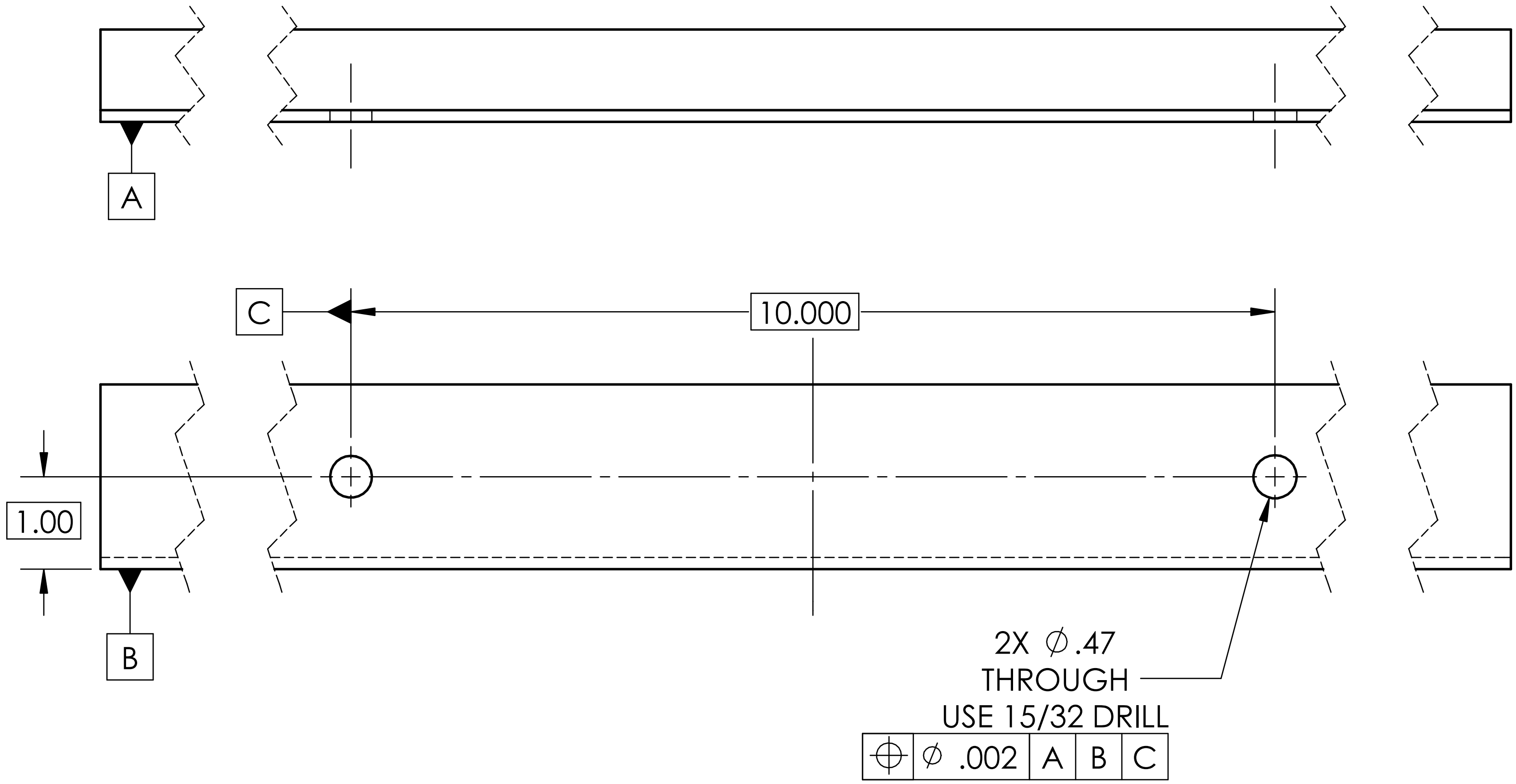
TITLE:
ANGLE SUPPORT MEMBERS

CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	A. FLEMING	02/23/21
CHECKED:	A. FLEMING	06/06/21
APPROVED:	J. DAVIS	06/07/21

DWG. NO.: 111.50		PRT. NO.: 111.50	
NXT. ASB.: 111.00	SCALE: 1:1	SHEET 1 OF 1	

NOTES:
FROM DWG. NO. 111.50 CUT LIST
BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

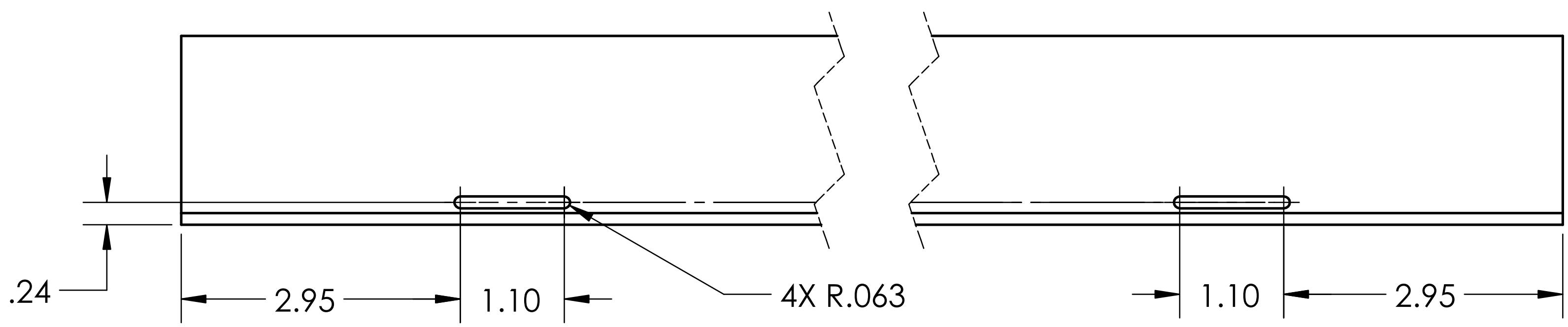
TITLE:
LOWER DECK
PAYLOAD BOX SUPPORT

CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	A. FLEMING	02/24/21
CHECKED:	A. FLEMING	06/06/21
APPROVED:	J. DAVIS	06/07/21

DWG. NO.: 111.5B		PRT. NO.: 111.5B	
NXT. ASB.: 111.00	SCALE: 1:2	SHEET 1 OF 1	

NOTES:
FROM DWG. NO. 111.50 CUT LIST
BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

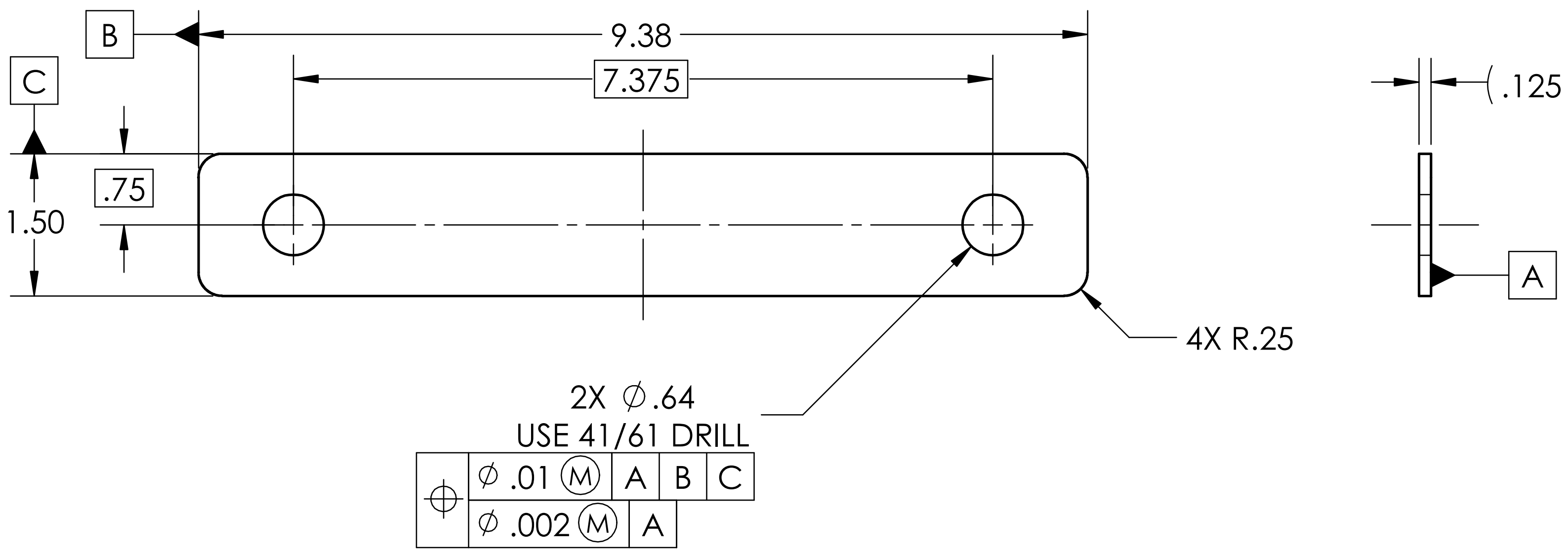
TITLE:
LOWER DECK
BATTERY SUPPORT

CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	A. FLEMING	02/24/21
CHECKED:	A. FLEMING	06/06/21
APPROVED:	J. DAVIS	06/07/21

DWG. NO.: 111.5C		PRT. NO.: 111.5C	
NXT. ASB.: 111.00	SCALE: 1:2	SHEET 1 OF 1	

NOTES:
USE ALUMINUM SHEET STOCK .1 INCH THICK
BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

U BOLT MOUNT PLATE

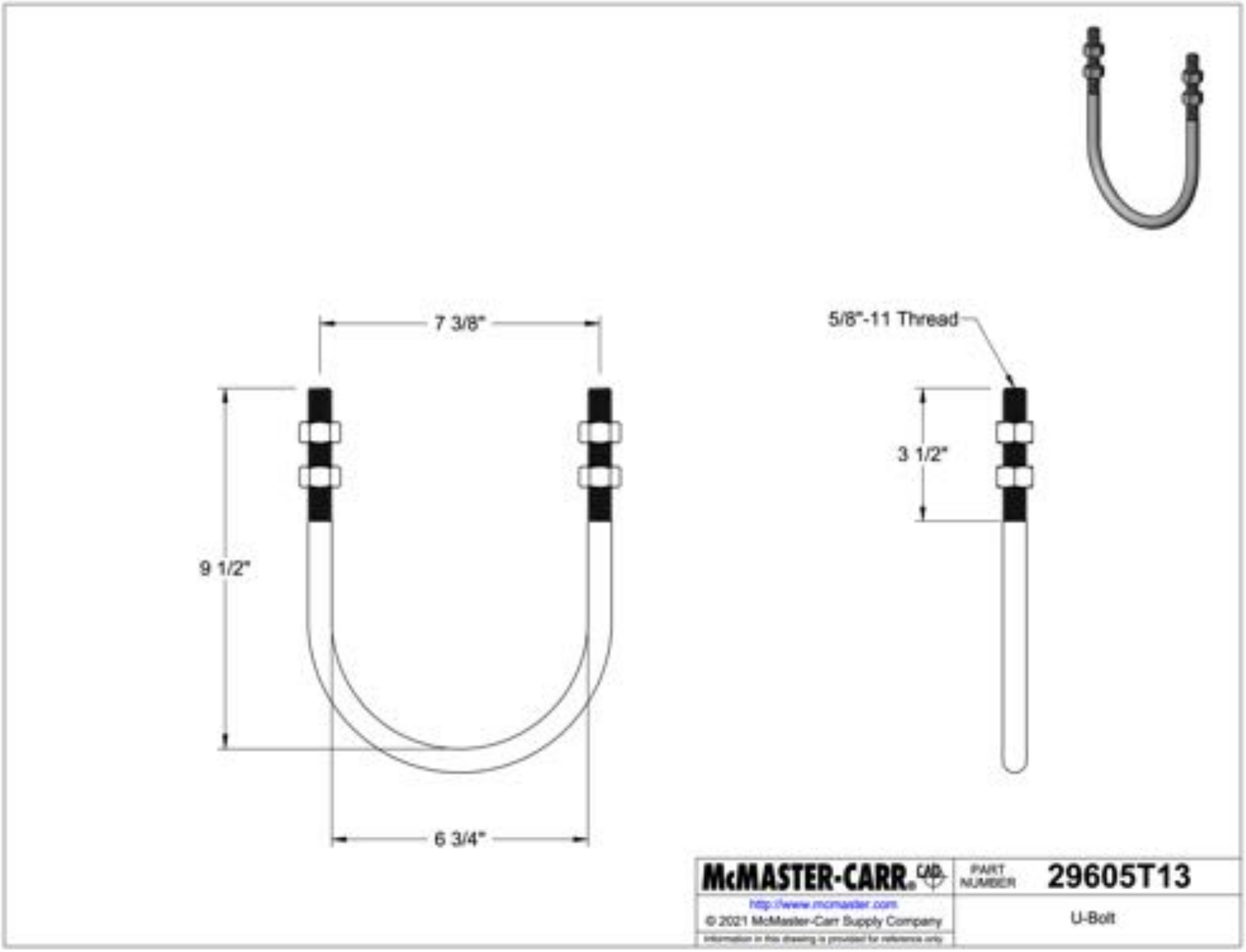
CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	A. FLEMING	02/23/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	J. DAVIS	06/07/21

DWG. NO.:	111.60	PRT. NO.:	111.60
NXT. ASB.: 111.00	SCALE: 1:2	SHEET 1 OF 1	

COMPONENT SPECIFICATION SHEET	Assembly	Frame	Date
Component 111.70: Lift Point U Bolt 316 Stainless Steel U Bolt – 5/18-11	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:



Specification Table:

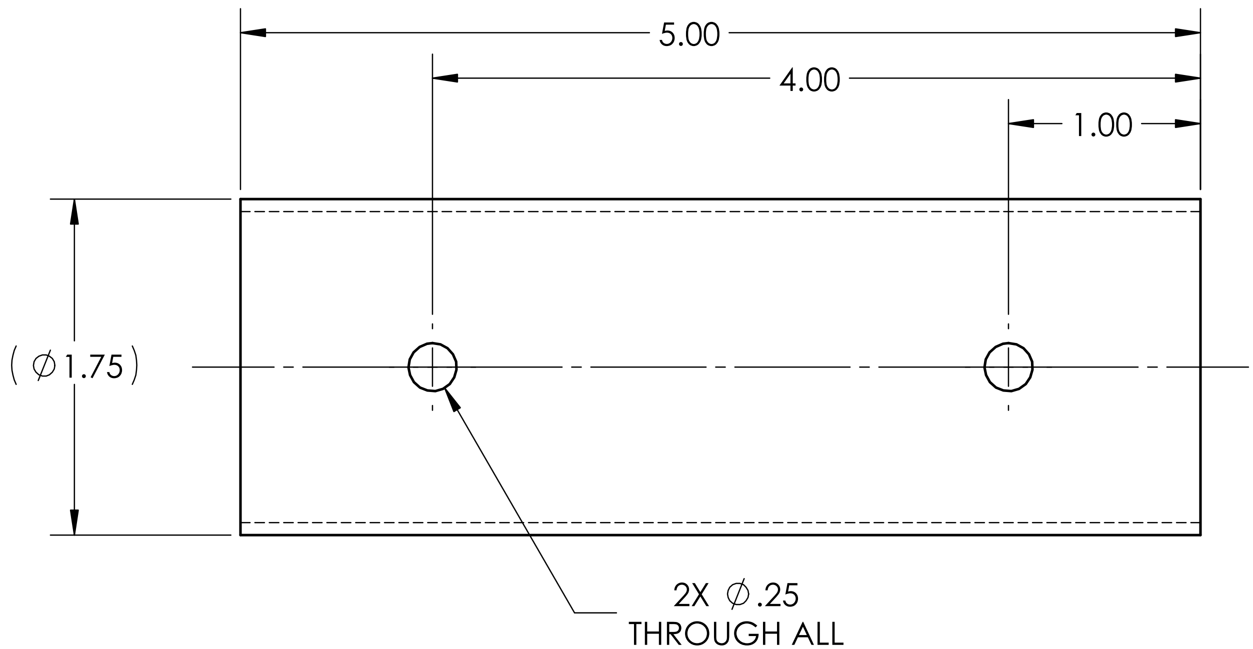
Parameter	Value
Material	316 Stainless Steel
Capacity	3,550 lbs

Notes:

∴ Includes 4 hex nuts made of 316 Stainless Steel.

NOTES:
USE AL. 6061-T6 TUBE STOCK
1.75 INCH OD X .065 INCH WALL THICKNESS

BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE: FLASH POLE MOUNTING TUBE

CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	A. FLEMING	02/23/21
CHECKED:	A. FLEMING	06/06/21
APPROVED:	J. DAVIS	06/07/21

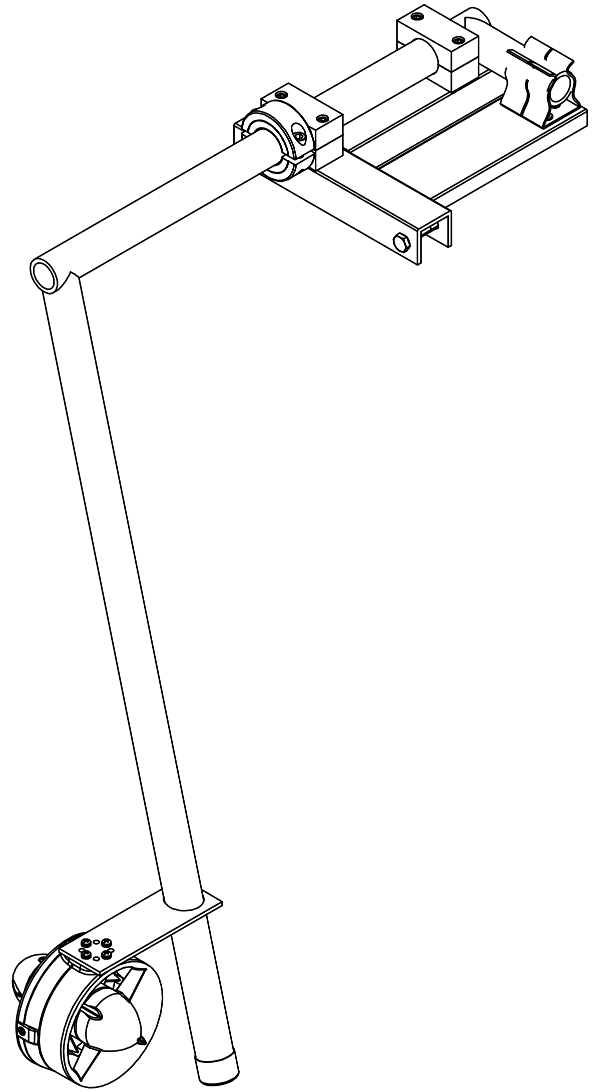
DWG. NO.:	111.80	PRT. NO.:	111.80		
NXT. ASB.:	111.00	SCALE:	1:1	SHEET 1 OF 1	

COMPONENT SPECIFICATION SHEET	Assembly	Frame	Date
Component 111.90: Flash Pole Storage Clips SeaLux Boat Hook Spring Clamp (Large)	Prepared	L. Vickerman	06/01/2021
	Checked	J. Davis	06/06/2021
	Approved	J. Davis	06/06/2021

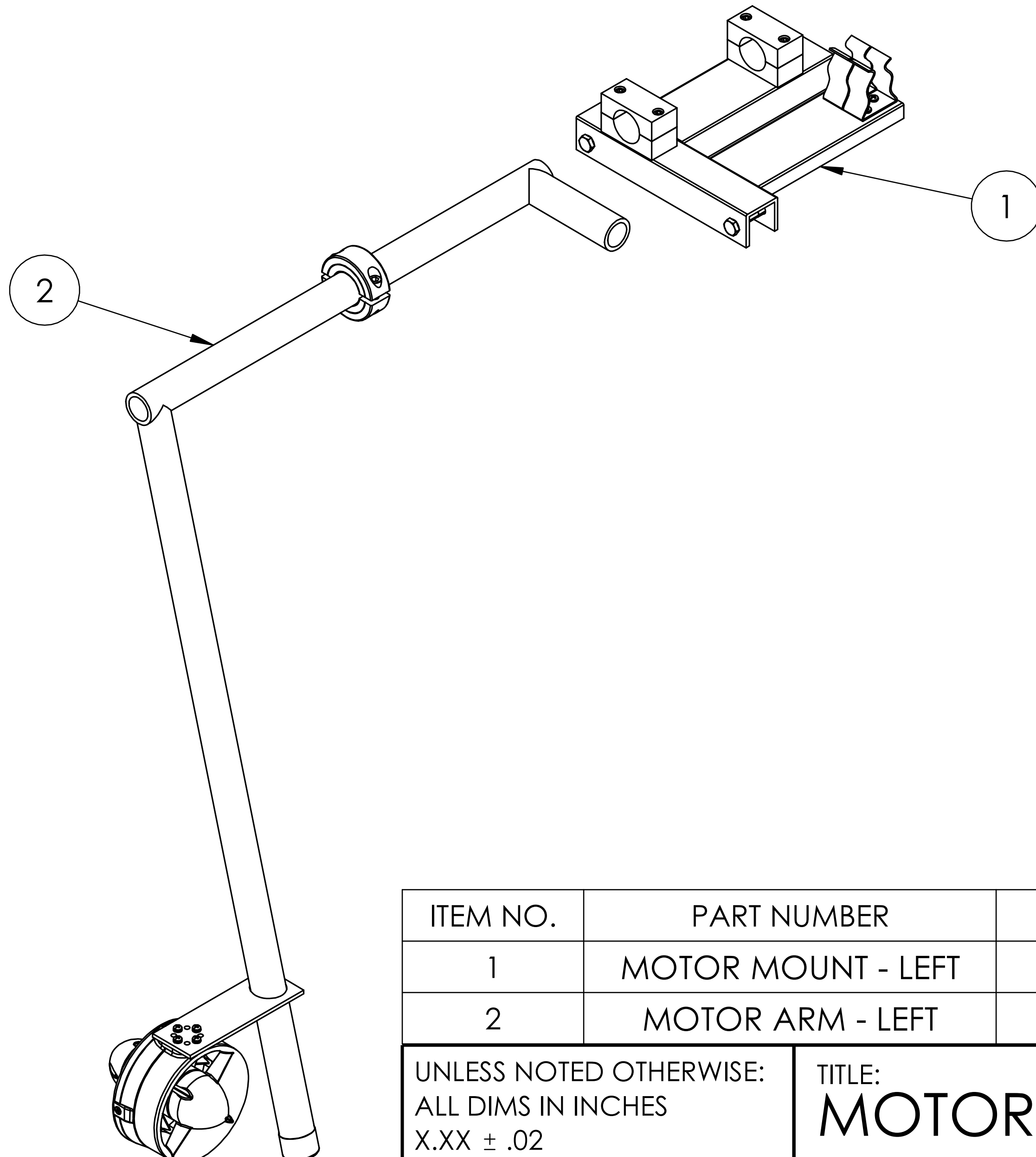
Visual Reference:

Notes:

∴ Made from 304 stainless steel
∴ Minimum clip I.D. 1-1/8" and maximum clip I.D. 1-3/4"
∴ Requires #6 RHMS fasteners
∴ Sold in a pack of 2



UNLESS NOTED OTHERWISE: ALL DIMS IN INCHES X.XX ± .02 X.XXX ± .005			TITLE: MOTOR ATTACHMENT LEFT	
CAL POLY SENIOR PROJECT Research Raft SEPT 2020 - JUNE 2021		NAME	DATE	DWG. NO.: 112.00	PRT. NO.: 112.00
	DRAWN:	K. YU	06/07/21	
	CHECKED:	A. FLEMING	06/07/21	NXT. ASB.: 110.00	SCALE: 1:5	SHEET 1 OF 2
	APPROVED:	A. FLEMING	06/07/21	



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MOTOR MOUNT - LEFT	112.30	1
2	MOTOR ARM - LEFT	112.40	1

UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:
MOTOR ATTACHMENT LEFT

CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K. YU	06/07/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 112.00-E		PRT. NO.: 112.00-E	
NXT. ASB.: 110.00	SCALE: 1:5	SHEET 2 OF 2	

COMPONENT SPECIFICATION SHEET	Assembly	Motor Attachment	Date
Component 112.10: Motor Mount Frame Mounting Bolt 1/4"-20 x 1-5/8" Hex Bolt	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:

Specification Table:

Parameter	Value
Diameter / Thread Size	1/4"-20
Finish	Plain
Grade	18-8
Length	1-5/8"
Material	Stainless Steel
Thread	Coarse
Thread Type	Partial Thread
Type	Hex Cap Screw
Wrench Size	7/16"
Product Weight	0.0259 lb
Fastenal SKU	0172248

Notes:

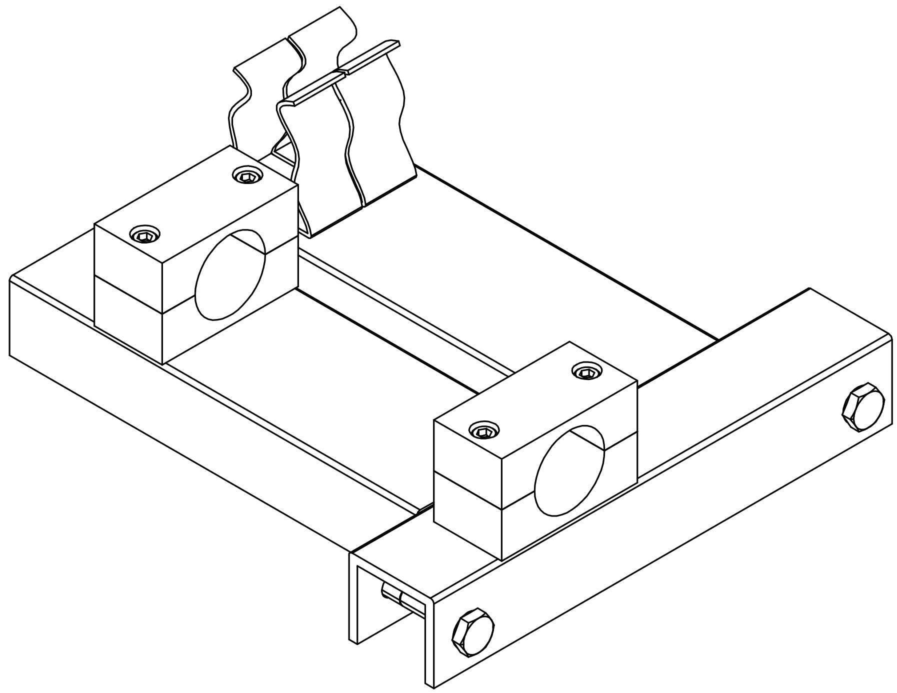
COMPONENT SPECIFICATION SHEET	Assembly	Motor Attachment	Date
Component 112.20: Motor Mount Frame Mounting Ny-Lock Nut 1/4"-20 Grade 316 NE Lock Nut	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:

Specification Table:

Parameter	Value
Diameter / Thread Size	1/4"-20
Finish	Plain
Grade	316
Material	Stainless Steel
Thickness	0.328"
Thread	Coarse
Type	Nylon Insert Lock Nut
Wrench Size	7/16"
Product Weight	0.0078 lb
Fastenal SKU	77860

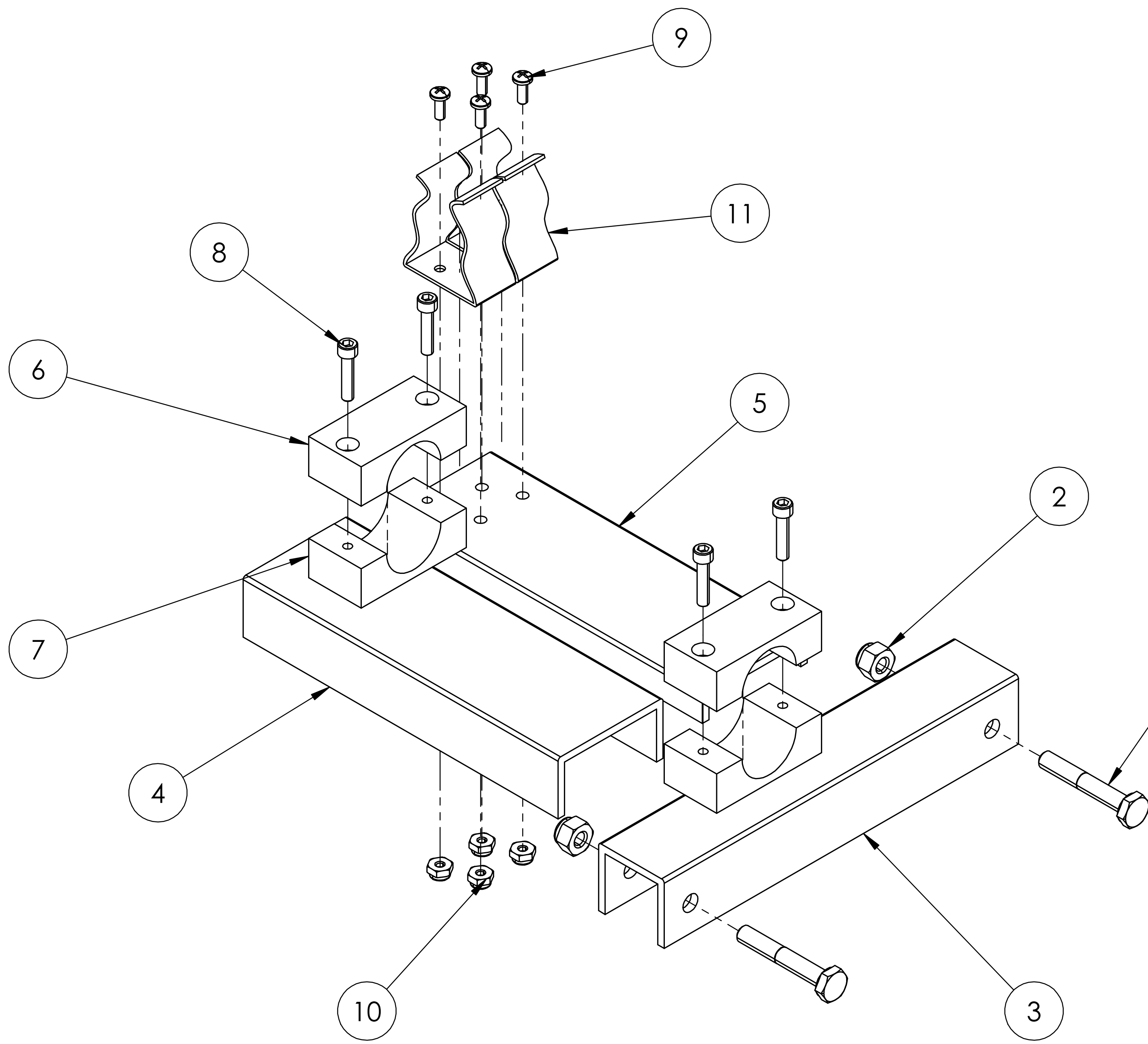
Notes:



UNLESS NOTED OTHERWISE: ALL DIMS IN INCHES X.XX ± .02 X.XXX ± .005	TITLE: MOTOR MOUNT - LEFT

CAL POLY SENIOR PROJECT Research Raft SEPT 2020 - JUNE 2021		NAME	DATE
	DRAWN:	K. YU	06/07/21
	CHECKED:	A. FLEMING	06/07/21
	APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 112.30		PRT. NO.: 112.30
NXT. ASB.: 112.00	SCALE: 1:2	SHEET 1 OF 3



ITEM NO.	PART NAME	PART NUMBER	QTY.
1	MOTOR MOUNT MOUNTING BOLT	112.10	2
2	MOTOR MOUNT MOUNTING NUT	112.20	2
3	FRAME MOUNT	112.31	1
4	HOLDER EXTENSION	112.32	1
5	CLIP EXTENSION	112.33	1
6	TOP HOLDER	112.34	2
7	BOTTOM HOLDER	112.35	2
8	HOLDER SOCKET SCREW	112.36	4
9	CLIP SCREW	112.37	4
10	CLIP NUT	112.38	4
11	CLIP	112.39	2

UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

MOTOR MOUNT - LEFT

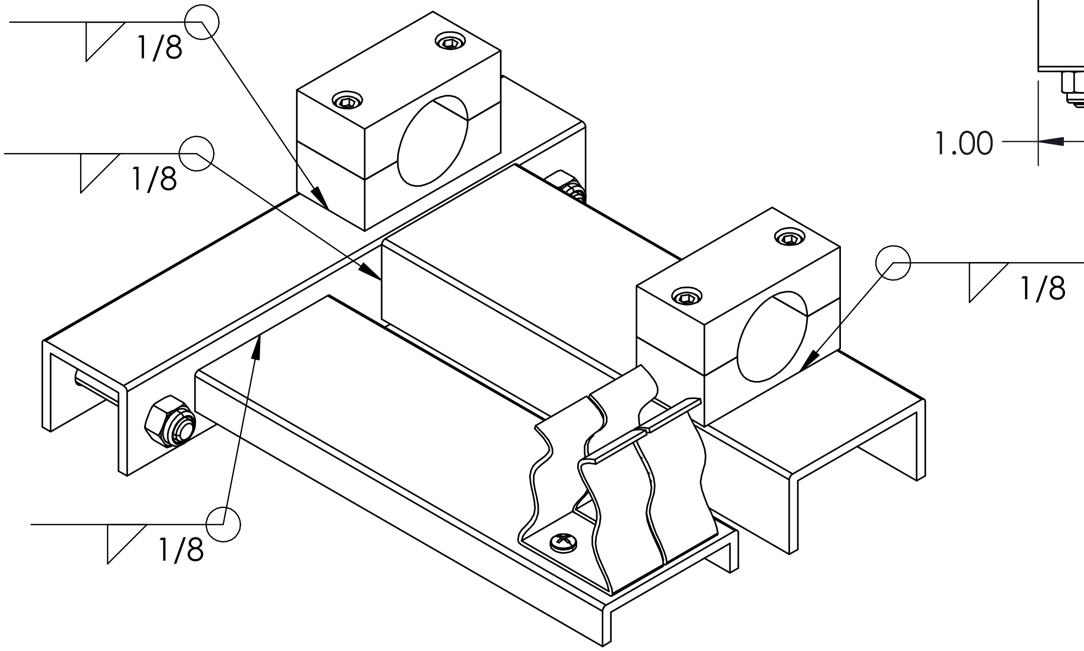
CAL POLY SENIOR PROJECT

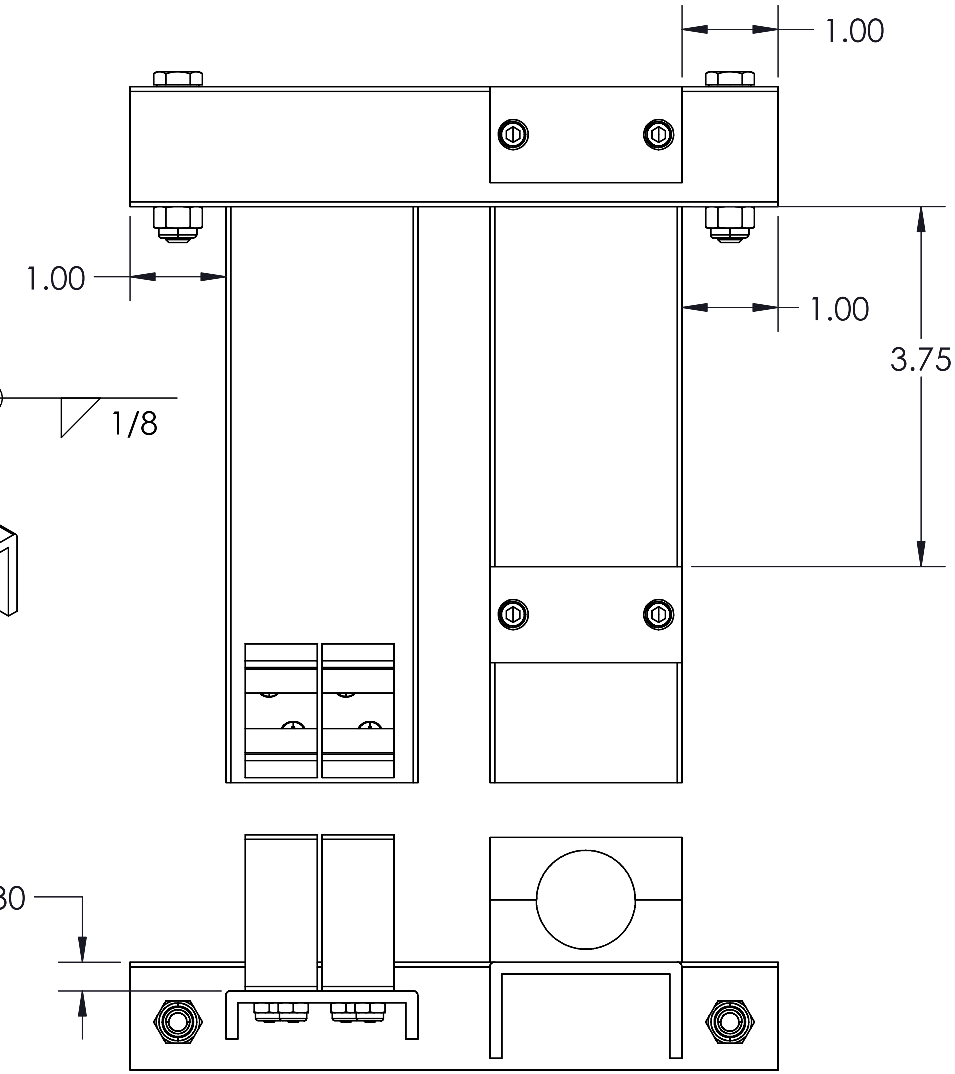
Research Raft

SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K. YU	06/07/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 112.30-E		PRT. NO.: 112.30-E	
NXT. ASB.: 112.00	SCALE: 1:2		SHEET 2 OF 3





NOTES:
USE 5356 FILLER ROD

USE COMPLETE MOTOR ARM TO POSITION THE HOLDER CLOSEST TO THE CLIP BEFORE WELDING

UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:
MOTOR MOUNT - LEFT

CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

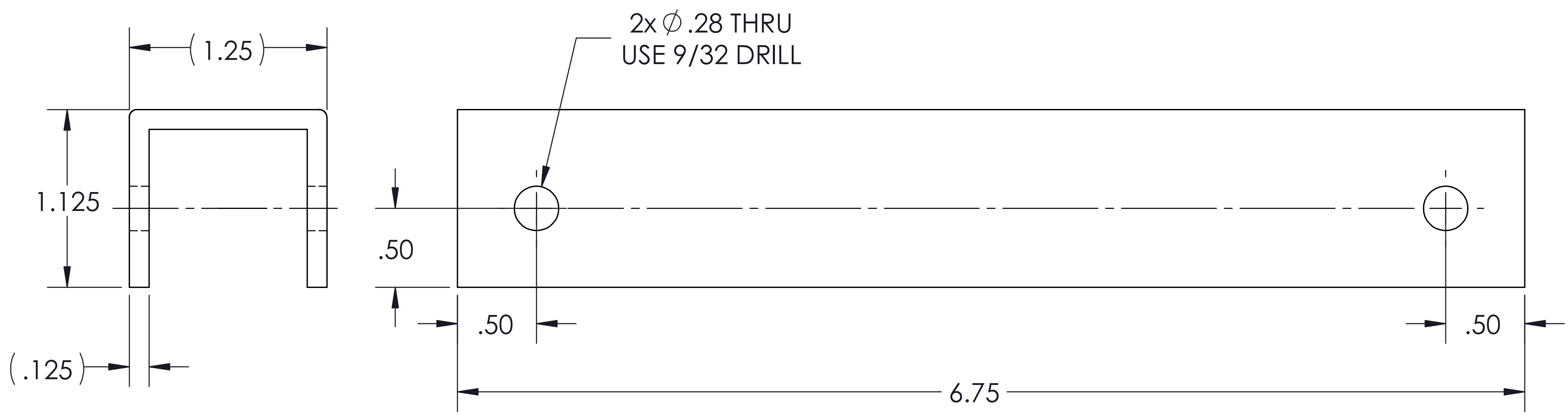
	NAME	DATE
DRAWN:	K. YU	06/07/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 112.30-W		PRT. NO.: 112.30-W	
NXT. ASB.: 112.00	SCALE: 1:2	SHEET 3 OF 3	

NOTES:

USE 1.25 INCH X 1.25 INCH 6063 ALUMINUM C-CHANNEL WITH .125 INCH THICKNESS
MACHINE DOWN CHANNEL LEGS TO 1.125 INCHES

BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

FRAME MOUNT

CAL POLY SENIOR PROJECT

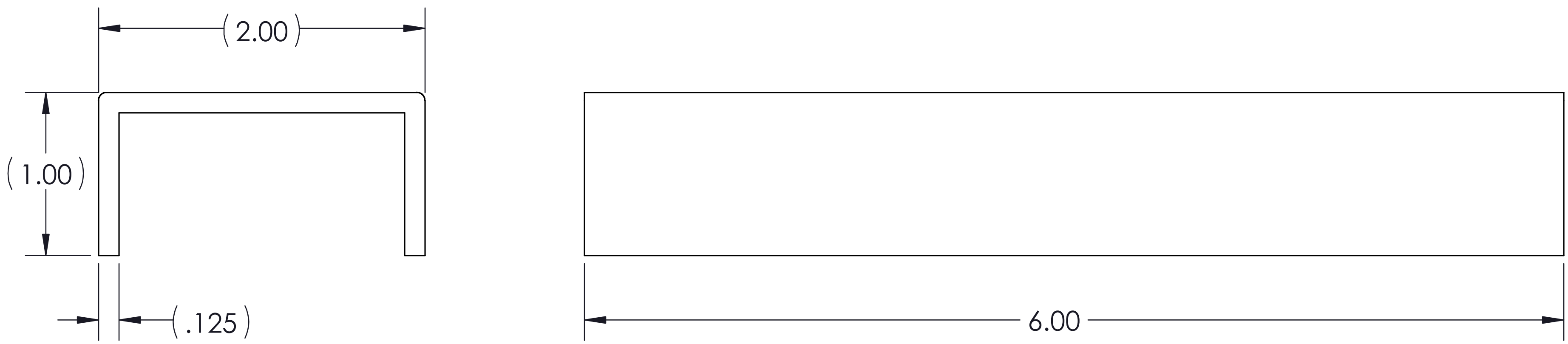
Research Raft

SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K.YU	05/29/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.:	112.31	PRT. NO.:	112.31
NXT. ASB.: 112.30	SCALE: 1:1	SHEET 1 OF 1	

NOTES:
USE 2 INCH X 1 INCH 6063 ALUMINUM C-CHANNEL .125 INCH THICK
BREAK SHARP EDGES MAX .01



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

HOLDER EXTENSION

CAL POLY SENIOR PROJECT

Research Raft

SEPT 2020 - JUNE 2021

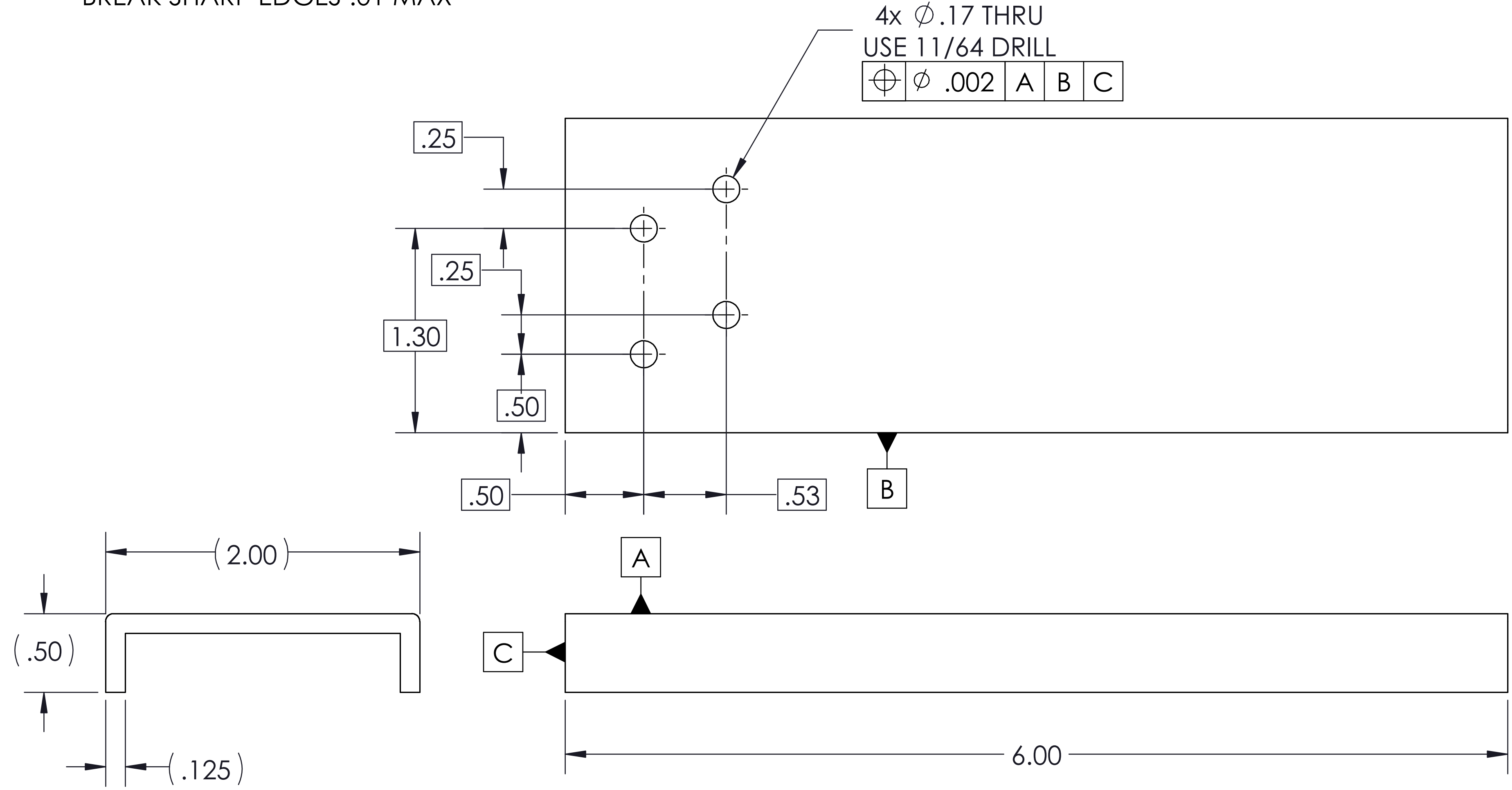
	NAME	DATE
DRAWN:	K. YU	06/07/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 112.32	PRT. NO.: 112.32	
NXT. ASB.: 112.30	SCALE: 1:1	SHEET 1 OF 1

NOTES:

USE 2 INCH x .5 INCH C-CHANNEL WITH .125 INCH THICKNESS

BREAK SHARP EDGES .01 MAX

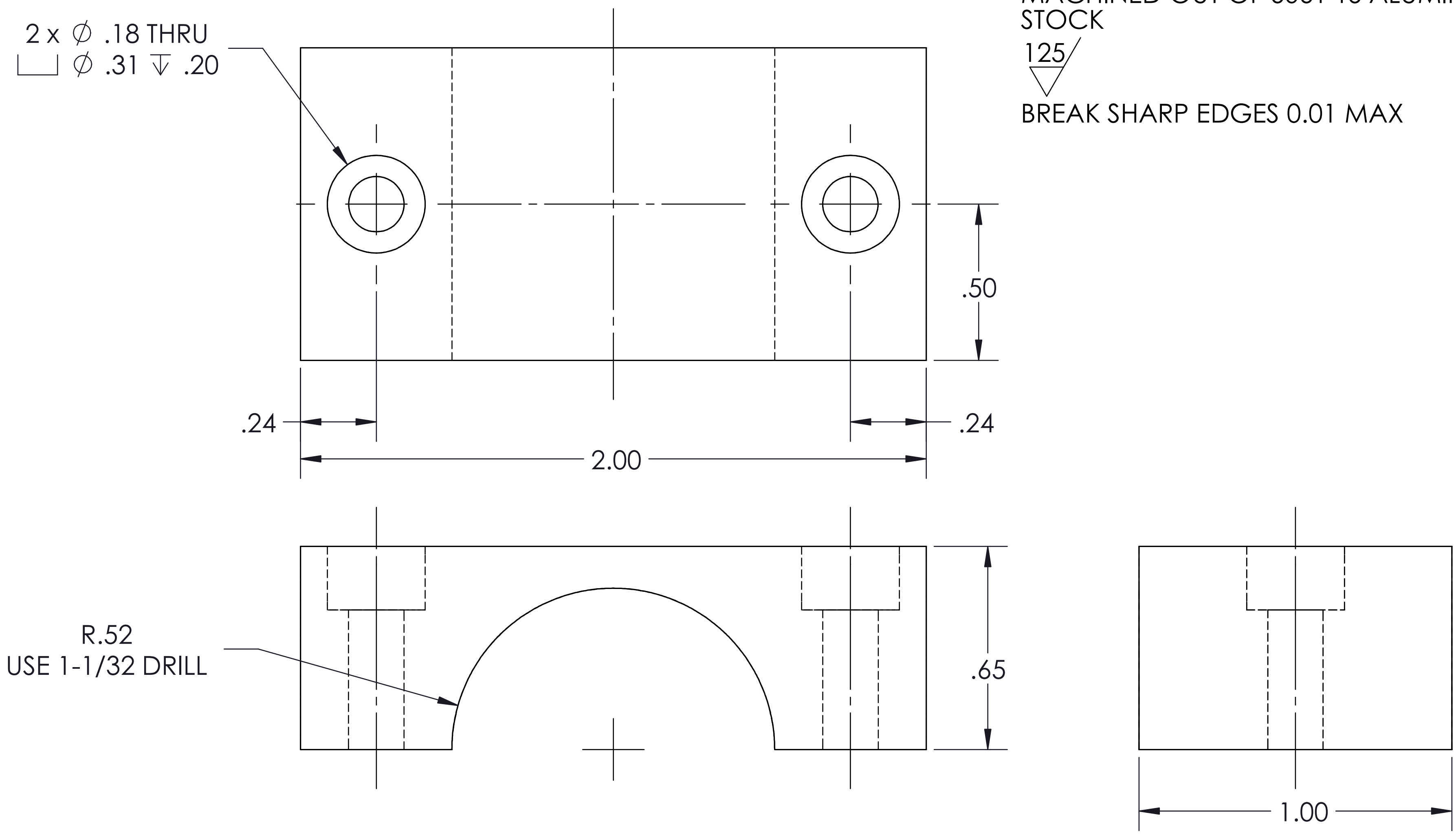


UNLESS NOTED OTHERWISE: ALL DIMS IN INCHES X.XX ± .02 X.XXX ± .005	TITLE: CLIP EXTENSION	

CAL POLY SENIOR PROJECT Research Raft SEPT 2020 - JUNE 2021		NAME	DATE
	DRAWN:	K.YU	05/29/21
	CHECKED:	A. FLEMING	06/07/21
	APPROVED:	A. FLEMING	06/07/21

DWG. NO.:	112.33	PRT. NO.:	112.33		
NXT. ASB.:	112.30	SCALE:	1:1	SHEET 1 OF 1	

NOTES:
MACHINED OUT OF 6061-T6 ALUMINUM STOCK
125
BREAK SHARP EDGES 0.01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

Top Holder

CAL POLY SENIOR PROJECT

Research Raft

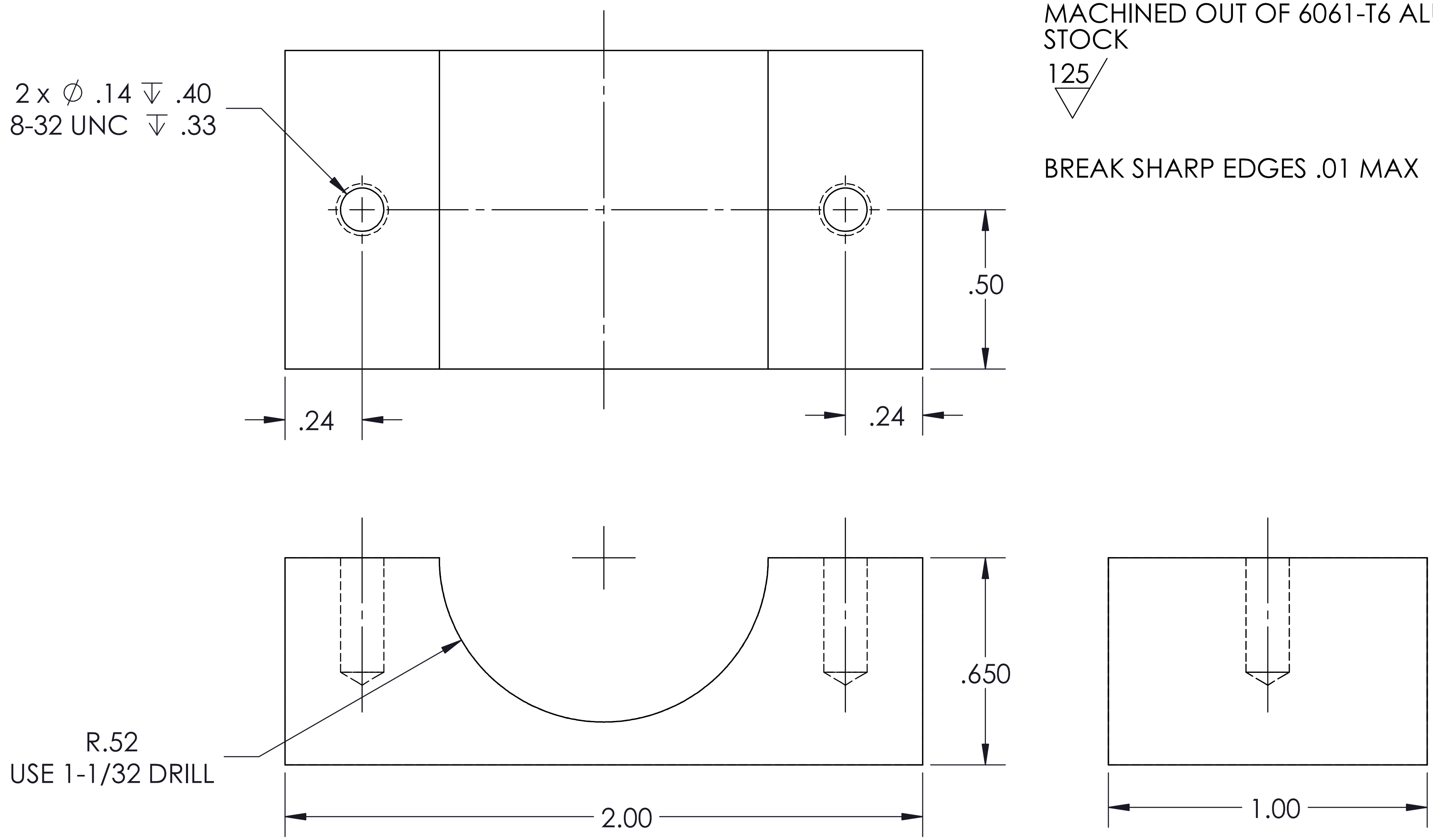
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K. YU	02/24/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 112.34		PRT. NO.: 112.34	
NXT. ASB.: 112.30	SCALE: 2:1	SHEET 1 OF 1	

NOTES:
MACHINED OUT OF 6061-T6 ALUMINUM STOCK
125

BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

BOTTOM HOLDER

CAL POLY SENIOR PROJECT

Research Raft

SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K. YU	02/24/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.:	112.35	PRT. NO.:	112.35		
NXT. ASB.:	112.30	SCALE:	2:1	SHEET 1 OF 1	

COMPONENT SPECIFICATION SHEET	Assembly	Motor Mount	Date
Component 112.36: Motor Mount Holder Socket Screw #8-32 x 3/4” Hex Drive Socket Cap Screw	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:

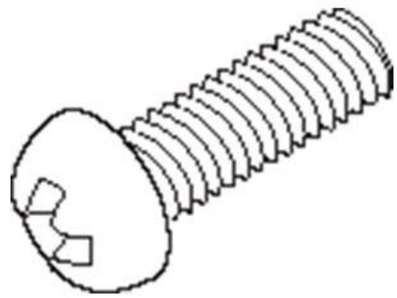
Specification Table:

Parameter	Value
Diameter / Thread Size	#8-32
Finish	Plain
Grade	316
Length	3/4”
Material	Stainless Steel
Thread	Coarse
Type	Socket Cap Screw
Drive	Hex
Drive Size	9/64”
Product Weight	0.0052 lb
Fastenal SKU	79014

Notes:

COMPONENT SPECIFICATION SHEET	Assembly	Motor Mount	Date
Component 112.37: Motor Arm Retention Clip Screw #6-32 x 3/8” Pan Head Machine Screw	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:



Specification Table:

Parameter	Value
Diameter / Thread Size	#6-32
Finish	Plain
Grade	316
Length	3/8”
Material	Stainless Steel
Head	Pan
Type	Machine Screw
Drive	Phillips
Thread Type	Fully Threaded
Product Weight	0.0022 lb
Fastenal SKU	0178569

Notes:

COMPONENT SPECIFICATION SHEET	Assembly	Motor Mount	Date
Component 112.38: Motor Arm Retention Clip Nut #6-32 Grade 316 NM Lock Nut	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:

Specification Table:

Parameter	Value
Diameter / Thread Size	#6-32
Finish	Plain
Grade	316
Material	Stainless Steel
Thickness	0.188”
Thread	Coarse
Type	Nylon Insert Lock Nut
Series	NM
Wrench Size	5/16”
Product Weight	0.0024 lb
Fastenal SKU	77855

Notes:

COMPONENT SPECIFICATION SHEET	Assembly	Motor Mount	Date
Component 112.39: Motor Arm Retention Clip Amarine Marine Spring Clip (Small)	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:

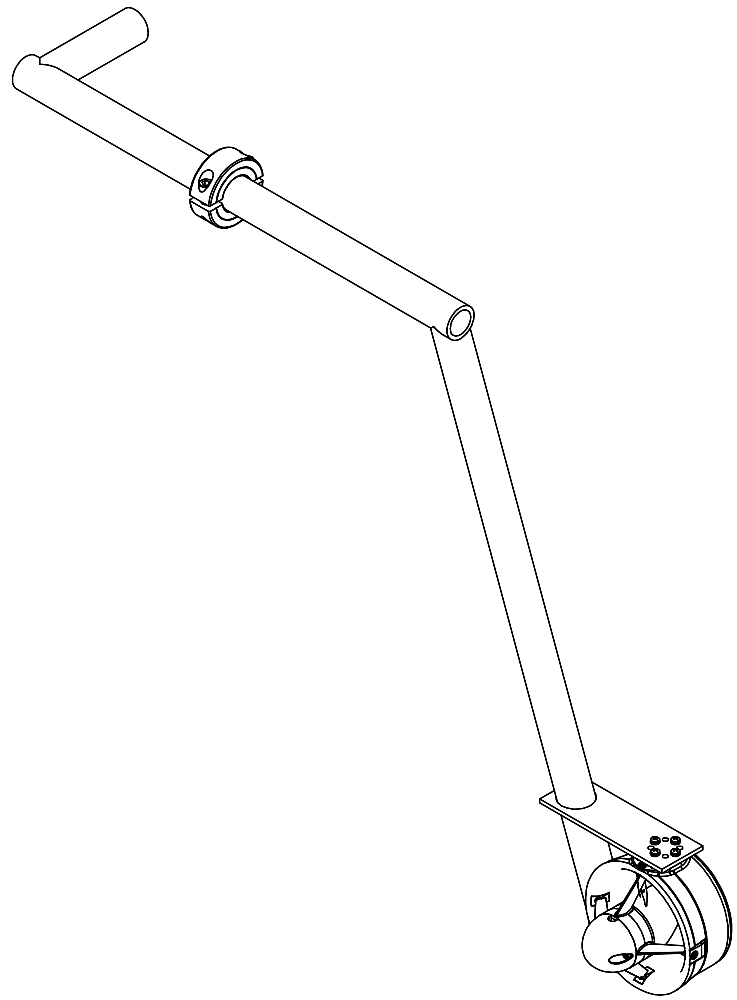
Specification Table:

Parameter	Value
Material	304 Stainless Steel
Required Fastener Size	#6 Screw

Notes:

∴ Sold as a pair.

∴ Each spring clip requires two #6 fasteners.



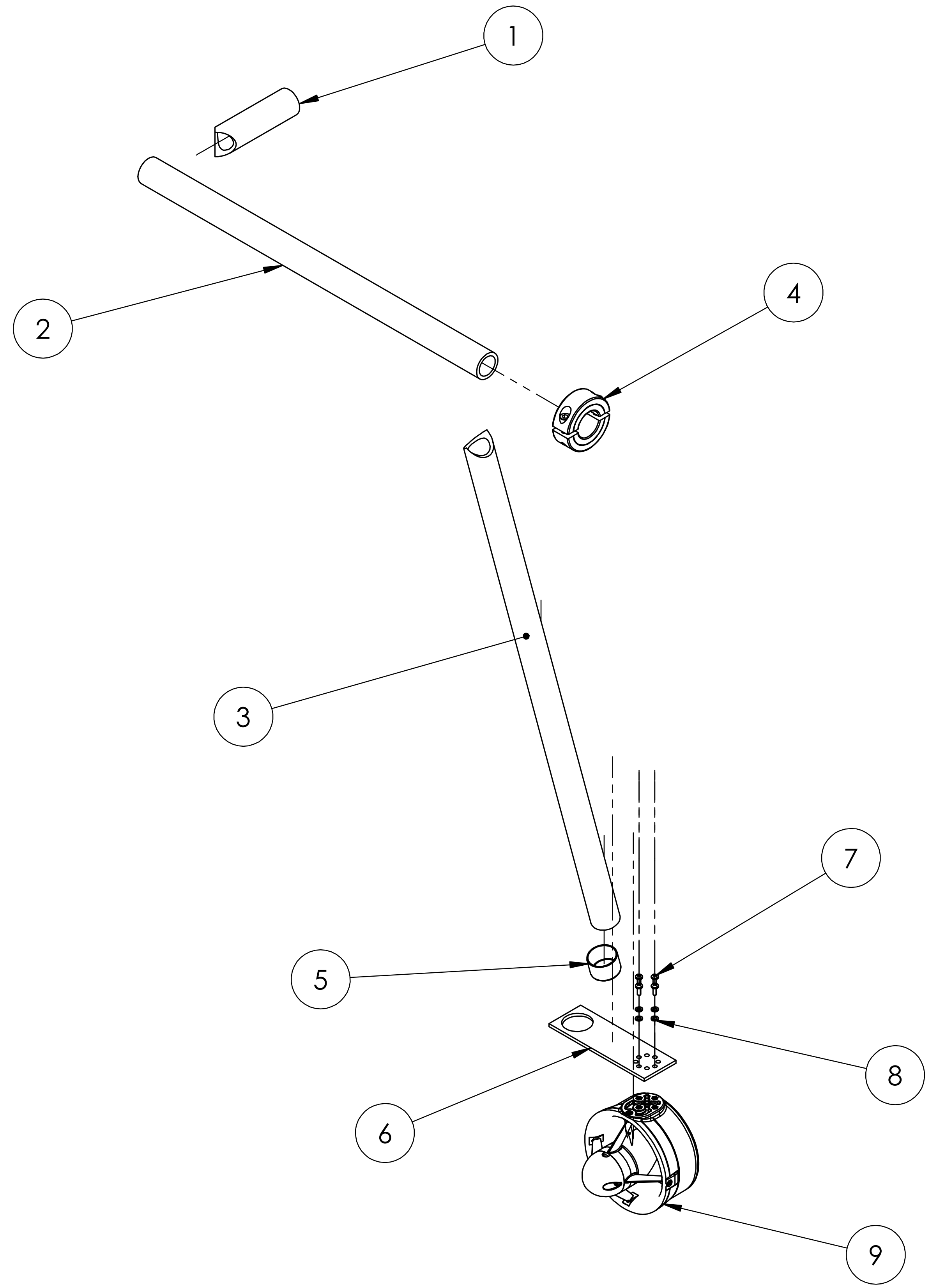
UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

MOTOR ARM - LEFT

CAL POLY SENIOR PROJECT		NAME	DATE
Research Raft	DRAWN:	K. YU	06/07/21
	CHECKED:	A. FLEMING	06/07/21
SEPT 2020 - JUNE 2021	APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 112.40	PRT. NO.: 112.40	
NXT. ASB.: 112.00	SCALE: 1:5	SHEET 1 OF 3



ITEM NO.	PART NAME	PART NUMBER	QTY.
1	ARM A	112.41	1
2	ARM B	112.42	1
3	ARM C	112.43	1
4	SHAFT COLLAR	112.44	1
5	TUBE END CAP	112.45	1
6	MOTOR ARM PLATE - LEFT	112.46	1
7	THRUSTER SCREW	112.50	4
8	THRUSTER LOCK WASHER	112.60	4
9	THRUSTER	112.70	1

UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

MOTOR ARM - LEFT

CAL POLY SENIOR PROJECT

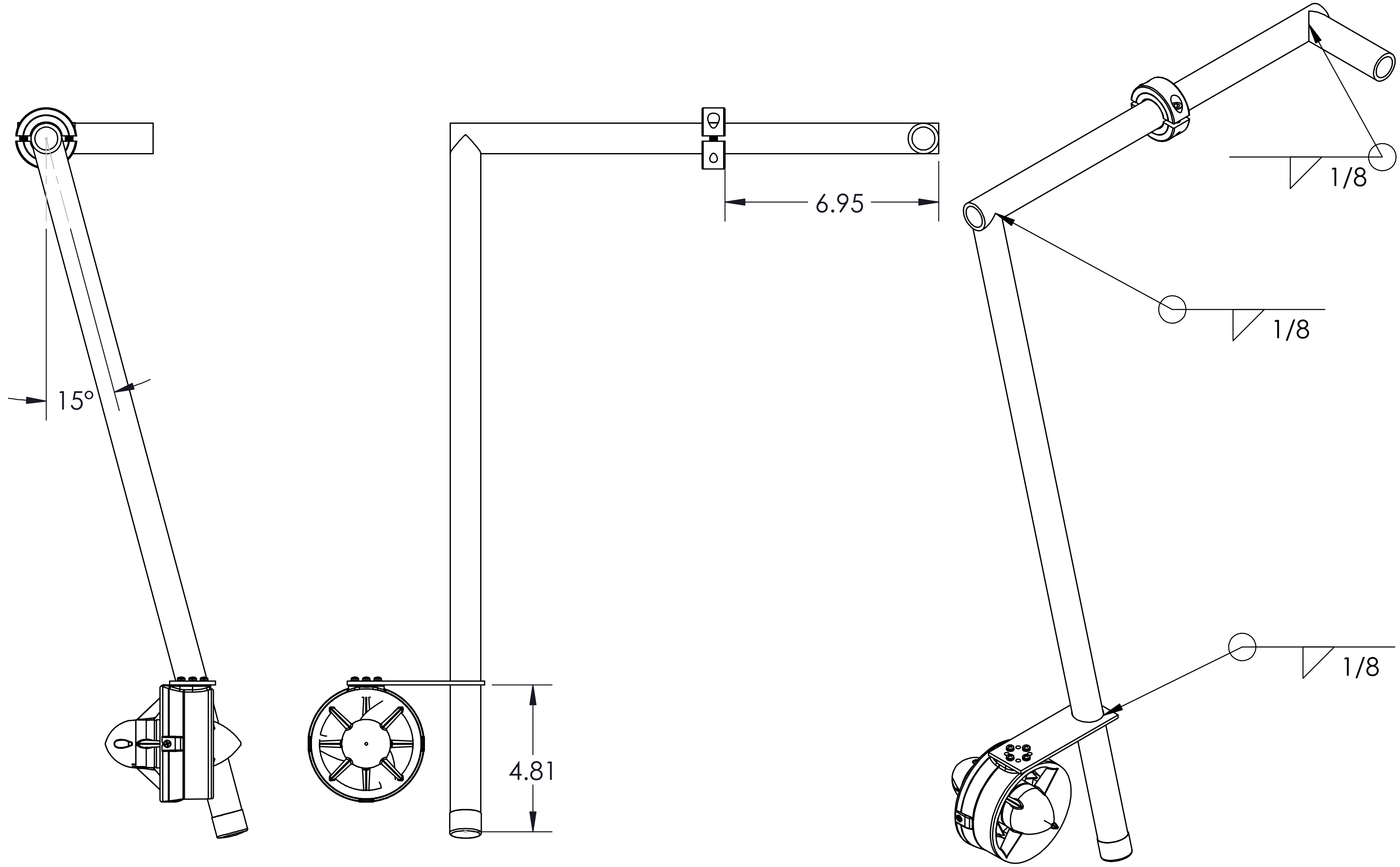
Research Raft

SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K. YU	06/07/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 112.40-E | PRT. NO.: 112.40-E

NXT. ASB.: 112.00 | SCALE: 1:5 | SHEET 2 OF 3



NOTES:
USE FILLER ROD 5356

UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:
MOTOR ARM - LEFT

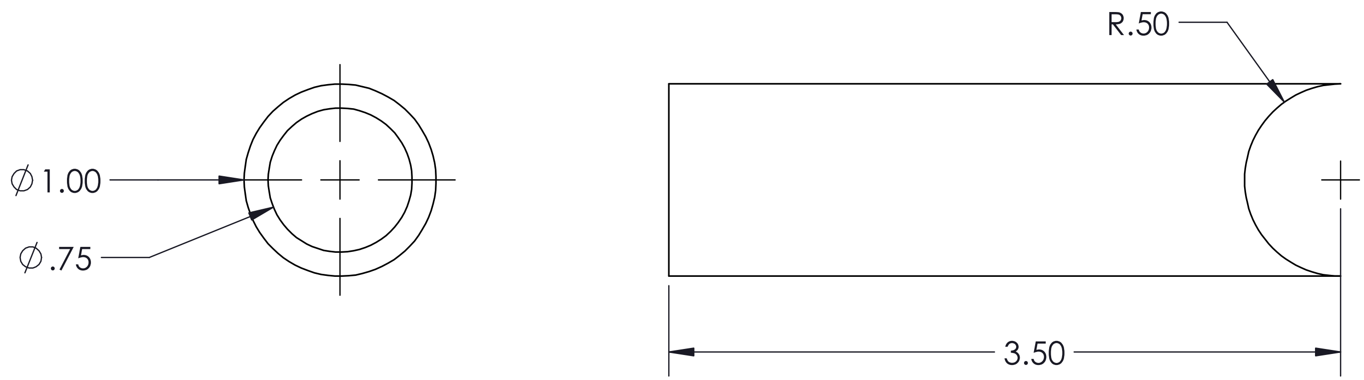
CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K. YU	06/07/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 112.40-W	PRT. NO.: 112.40-W	
NXT. ASB.: 112.00	SCALE: 1:5	SHEET 3 OF 3

NOTES:
USE 1 INCH OD X .125 INCH WT X .75 INCH ID
ALUMINUM 6061-T6 ROUND TUBE

BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

ARM A

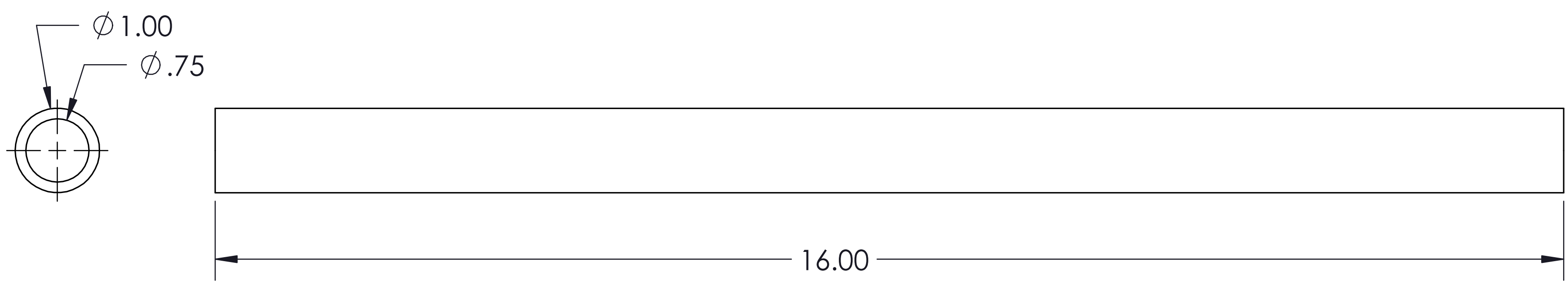
CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K. YU	02/24/21
CHECKED:	J. DAVIS	02/25/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 112.41		PRT. NO.: 112.41	
NXT. ASB.: 112.40	SCALE: 1:1	SHEET 1 OF 1	

NOTES:
USE 1 INCH OD X .125 INCH WT X .75 INCH ID
ALUMINUM 6061-T6 ROUND TUBE

BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

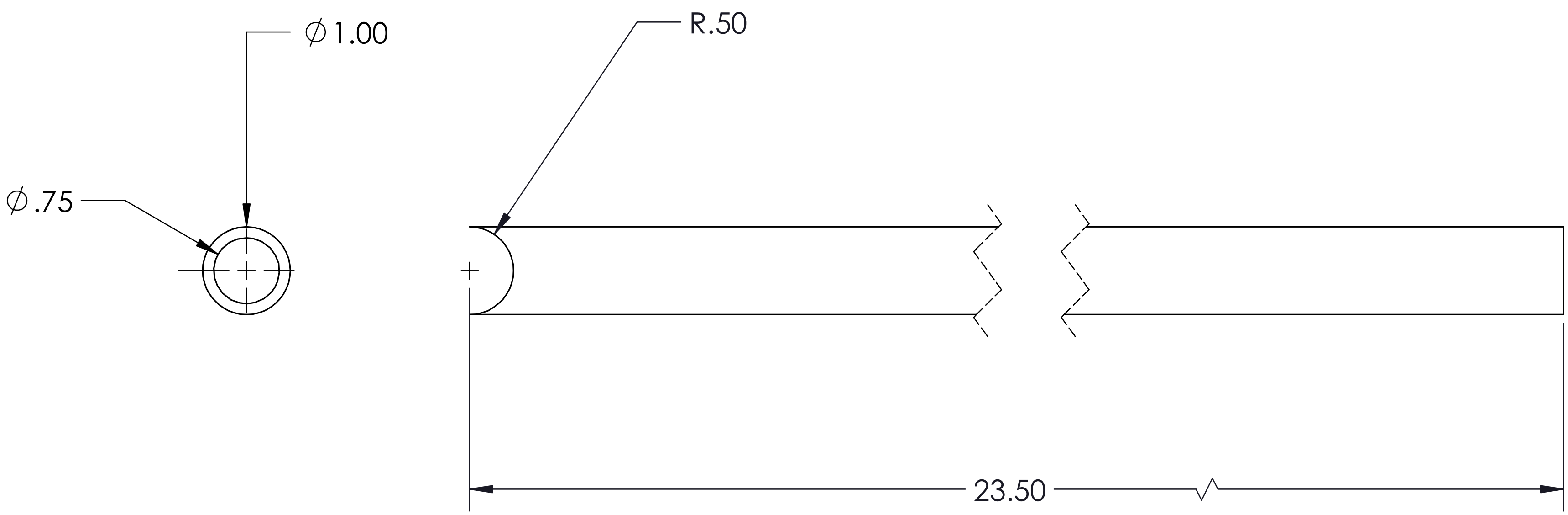
TITLE:
ARM B

CAL POLY SENIOR PROJECT		NAME	DATE
Research Raft	DRAWN:	K. YU	02/24/21
	CHECKED:	J. DAVIS	02/25/21
SEPT 2020 - JUNE 2021	APPROVED:	A. FLEMING	06/07/21

DWG. NO.:	112.42	PRT. NO.:	112.42		
NXT. ASB.:	112.40	SCALE:	1:2	SHEET 1 OF 1	

NOTES:
USE 1 INCH OD X .125 INCH WT X .75 INCH ID
ALUMINUM 6061-T6 ALUMINUM TUBE

BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

ARM C

CAL POLY SENIOR PROJECT

Research Raft

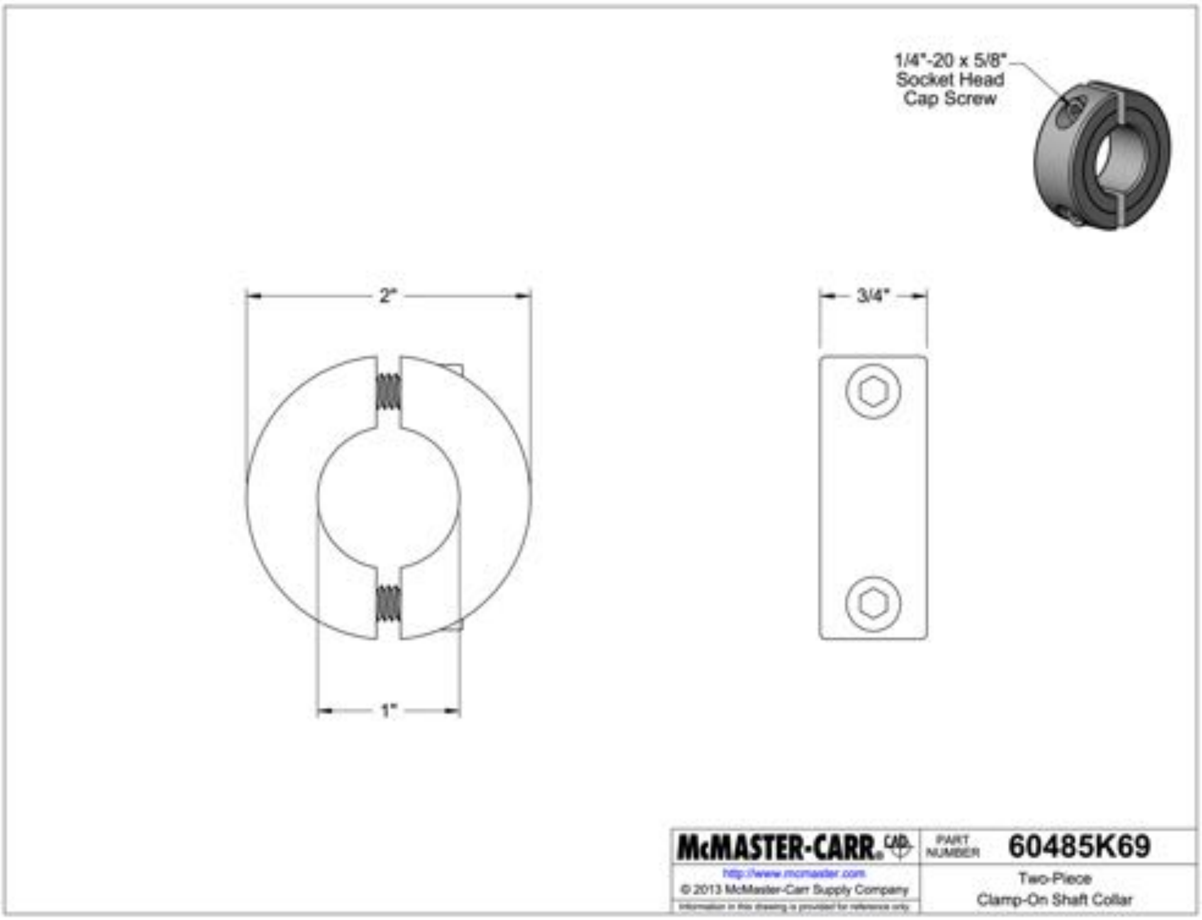
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K. YU	02/24/21
CHECKED:	J. DAVIS	02/25/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.:	112.43	PRT. NO.:	112.43		
NXT. ASB.:	112.40	SCALE:	1:4	SHEET 1 OF 1	

COMPONENT SPECIFICATION SHEET	Assembly	Motor Arm	Date
Component 112.44: Motor Arm Shaft Collar Washdown Clamping Two-Piece Shaft Collar	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:



Specification Table:

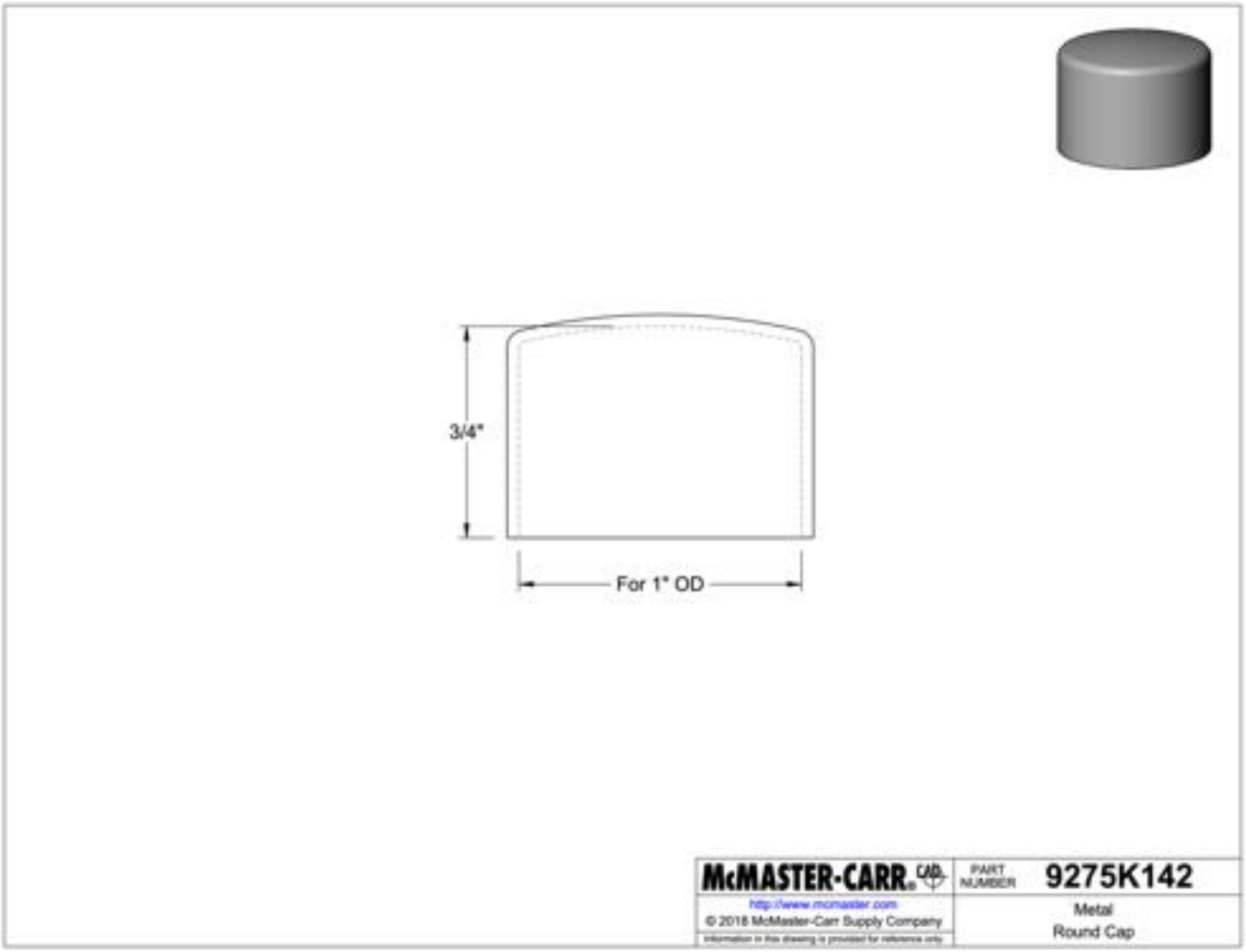
Parameter	Value
Material	White Nylon Plastic
Construction	Two Piece

Notes:

∴ Intended for 1" shaft diameter.
∴ 2 clamping screws.
∴ Clamping screws are socket head screws made out of 18-8 stainless steel.

COMPONENT SPECIFICATION SHEET	Assembly	Motor Arm	Date
Component 112.45: Motor Arm End Cap Metal Round Cap for 1" OD, Aluminum	Prepared	L. Vickerman	02/24/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:



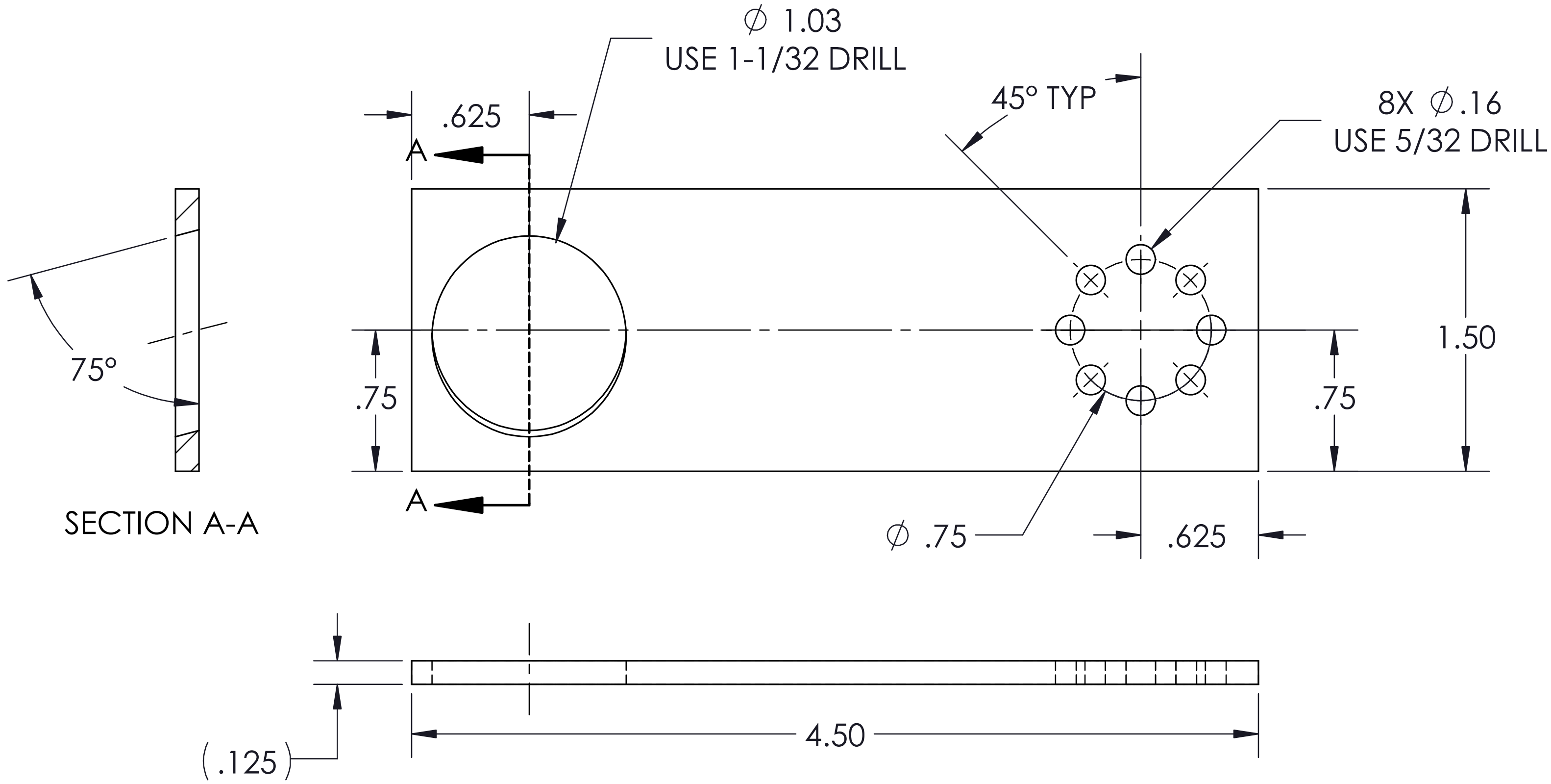
Specification Table:

Parameter	Value
Material	Aluminum
Inside Height	23/32"

Notes:

NOTES:
USE .125 INCH 6061-T6 ALUMINUM SHEET

BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

MOTOR ARM PLATE - LEFT

CAL POLY SENIOR PROJECT

Research Raft

SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K. YU	06/07/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 112.46		PRT. NO.: 112.46	
NXT. ASB.: 112.40	SCALE: 1:1	SHEET 1 OF 1	

COMPONENT SPECIFICATION SHEET	Assembly	Motor Attachment	Date
Component 112.50: Thruster Mounting Screw M3-0.5 x 8mm DIN 7985 Pan Head Machine Screw	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:

Specification Table:

Parameter	Value
Diameter / Thread Size	M3-0.5
Finish	Plain
Grade	A2
Length	8 mm
Material	Stainless Steel
Head	Pan
Type	Machine Screw
Drive	Phillips
Specification	DIN 7985
Product Weight	0.0016 lb
Fastenal SKU	QM2510008A20000

Notes:

COMPONENT SPECIFICATION SHEET	Assembly	Motor Attachment	Date
Component 112.60: Thruster Mounting Lock Washer M3 DIN 127 A2 Split Lock Washer	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:

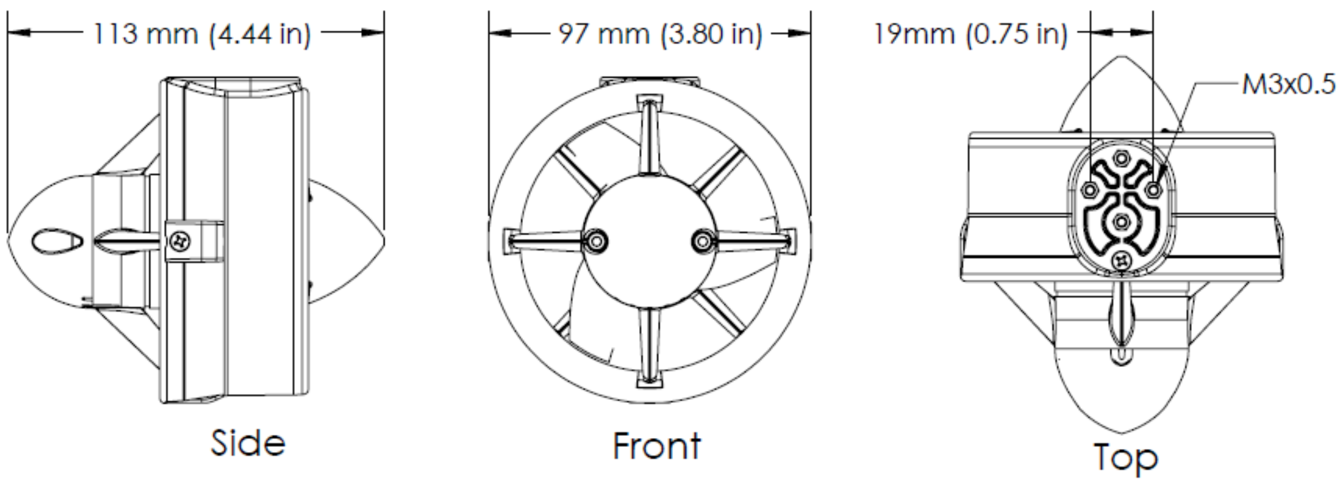
Specification Table:

Parameter	Value
Inner Diameter	3.40 mm
Finish	Plain
Grade	A2
Material	Stainless Steel
Nominal Size	M3
Nominal Thickness	0.80 mm
Outer Diameter	6.20 mm
Specification	DIN 127
Type	Split Lock Washer
Product Weight	0.0003 lb
Fastenal SKU	ML6330000A20000

Notes:

COMPONENT SPECIFICATION SHEET	Assembly	Motor Attachment	Date
Component 112.70: Blue Robotics T200 Thruster SKU: T200-THRUSTER-R2-RP	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:

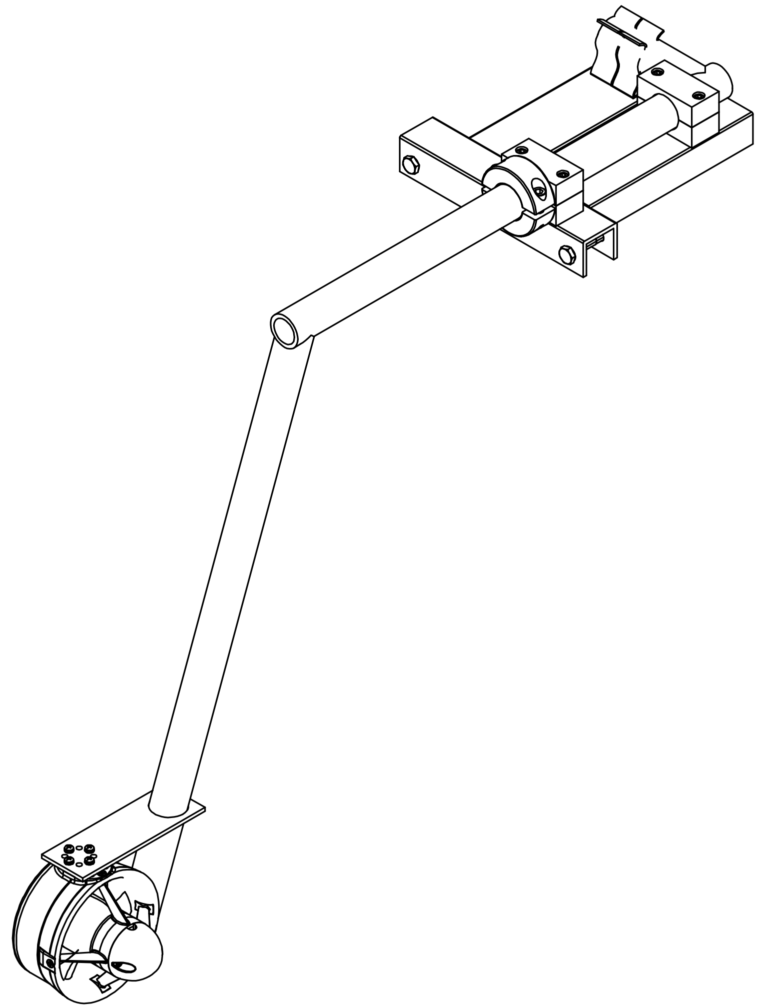


Specification Table:

Parameter	Value
Full Throttle FWD/REV Thrust @ Nominal (16 V)	11.6 / 9.0 lb f
Full Throttle FWD/REV Thrust @ Nominal (20 V)	14.8 / 11.1 lb f
Minimum Thrust	0.05 lb f
Operating Voltage	7-20 Volts
Full Throttle Current @ Nominal (16 V)	24 Amps
Full Throttle Current @ Maximum (20 V)	32 Amps
Full Throttle Power @ Nominal (16 V)	390 Watts
Full Throttle Power @ Maximum (20 V)	645 Watts
Weight in Air (with 1m cable)	0.76 lb
Weight in Water (with 1m cable)	0.34 lb
Propeller Diameter	3.0 in
Cable Length (Standard T200)	28 in
Cable Diameter	0.25 in

Notes:

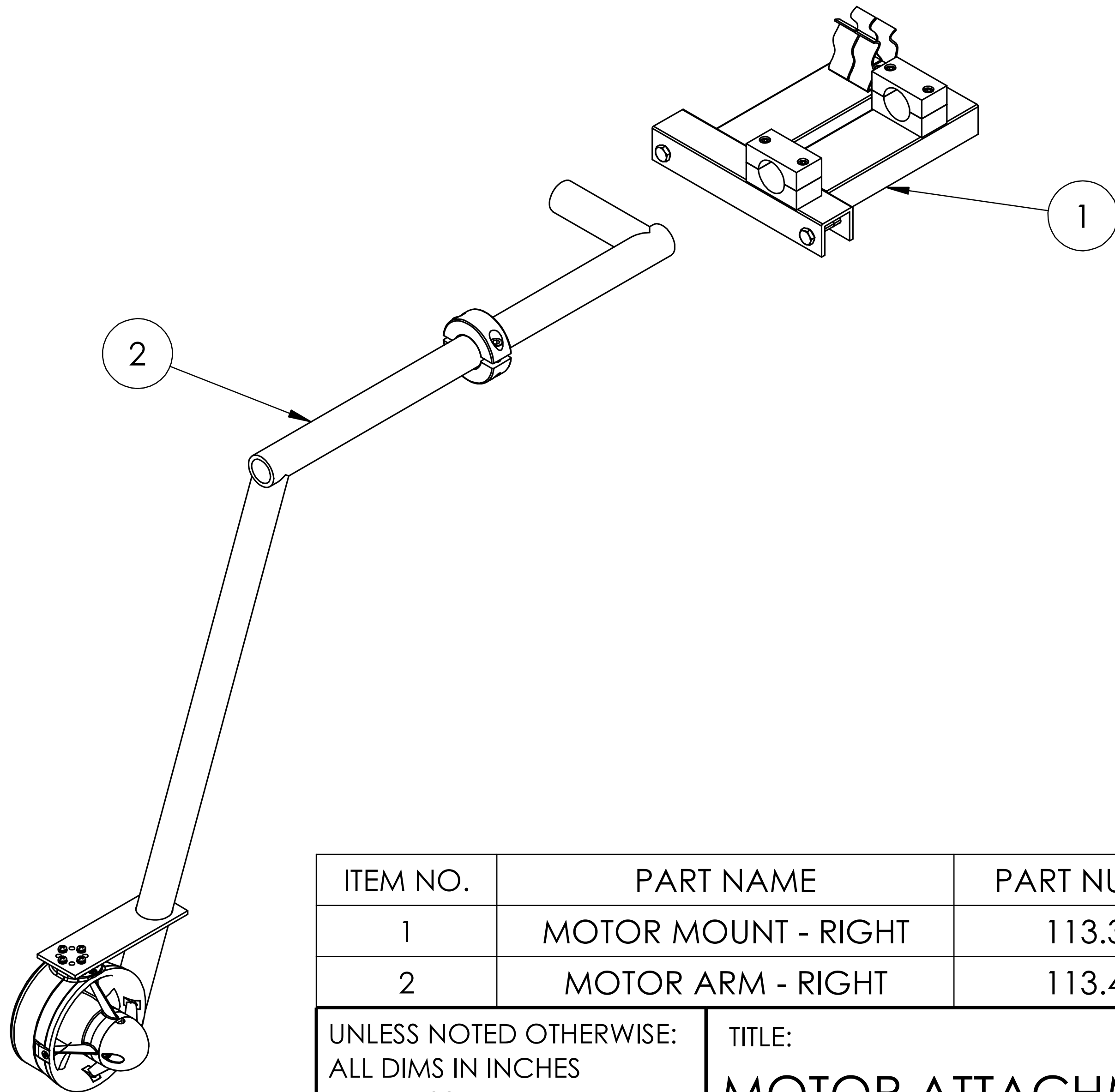
∴ Thruster comes with a clockwise and counterclockwise propeller.
∴ Thruster performance data can be found on the Blue Robotics website.



UNLESS NOTED OTHERWISE: ALL DIMS IN INCHES X.XX ± .02 X.XXX ± .005	TITLE: MOTOR ATTACHMENT RIGHT

		NAME	DATE
CAL POLY SENIOR PROJECT	DRAWN:	K.YU	06/07/21
Research Raft	CHECKED:	A. FLEMING	06/07/21
SEPT 2020 - JUNE 2021	APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 113.00	PRT. NO.: 113.00	
NXT. ASB.: 110.00	SCALE: 1:5	SHEET 1 OF 2



ITEM NO.	PART NAME	PART NUMER	QTY.
1	MOTOR MOUNT - RIGHT	113.30	1
2	MOTOR ARM - RIGHT	113.40	1

UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

MOTOR ATTACHMENT RIGHT

CAL POLY SENIOR PROJECT

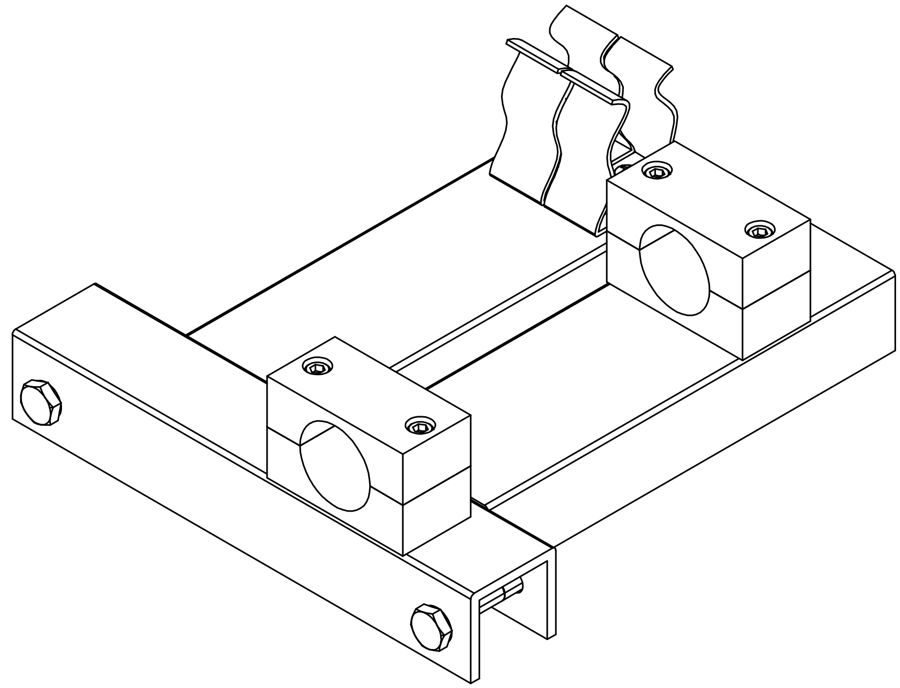
Research Raft

SEPT 2020 - JUNE 2021

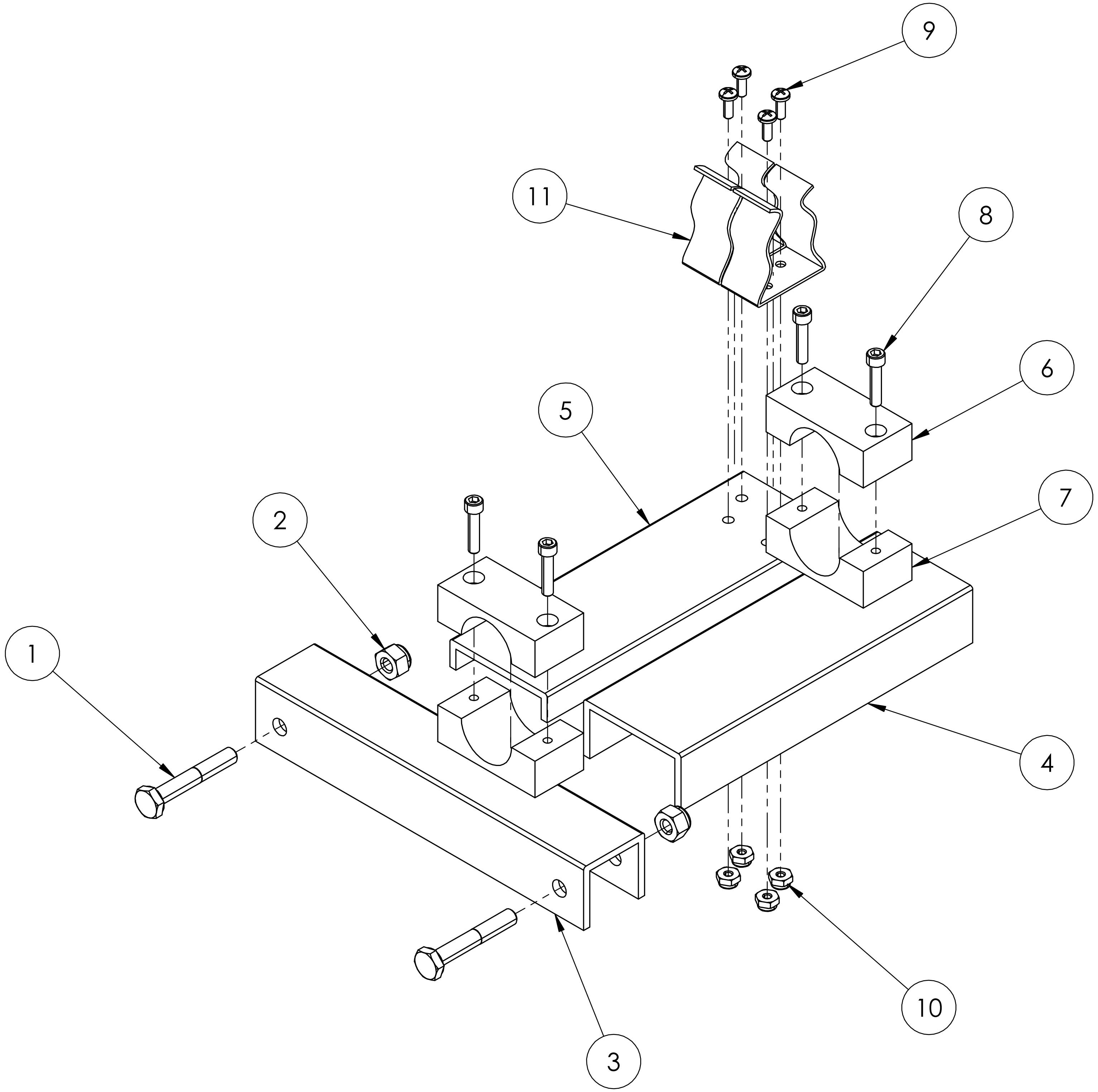
	NAME	DATE
DRAWN:	K. YU	06/07/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.:	113.00-E	PRT. NO.:	113.00-E

NXT. ASB.: 110.00	SCALE: 1:5	SHEET 2 OF 2



UNLESS NOTED OTHERWISE: ALL DIMS IN INCHES X.XX ± .02 X.XXX ± .005			TITLE: MOTOR MOUNT - RIGHT		
CAL POLY SENIOR PROJECT Research Raft SEPT 2020 - JUNE 2021		NAME	DATE		
	DRAWN:	K. YU	06/07/21	DWG. NO.: 113.30	PRT. NO.: 113.30
	CHECKED:	A. FLEMING	06/07/21	NXT. ASB.: 113.00	SCALE: 1:2
	APPROVED:	A. FLEMING	06/07/21	SHEET 1 OF 3	



ITEM NO.	PART NAME	PART NUMBER	QTY.
1	MOTOR MOUNT MOUNTING BOLT	112.10	2
2	MOTOR MOUNT MOUNTING NUT	112.20	2
3	FRAME MOUNT	112.31	1
4	HOLDER EXTENSION	112.32	1
5	CLIP EXTENSION	112.33	1
6	TOP HOLDER	112.34	2
7	BOTTOM HOLDER	112.35	2
8	HOLDER SOCKET SCREW	112.36	4
9	CLIP SCREW	112.37	4
10	CLIP NUT	112.38	4
11	CLIP	112.39	2

UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

MOTOR MOUNT - RIGHT

CAL POLY SENIOR PROJECT

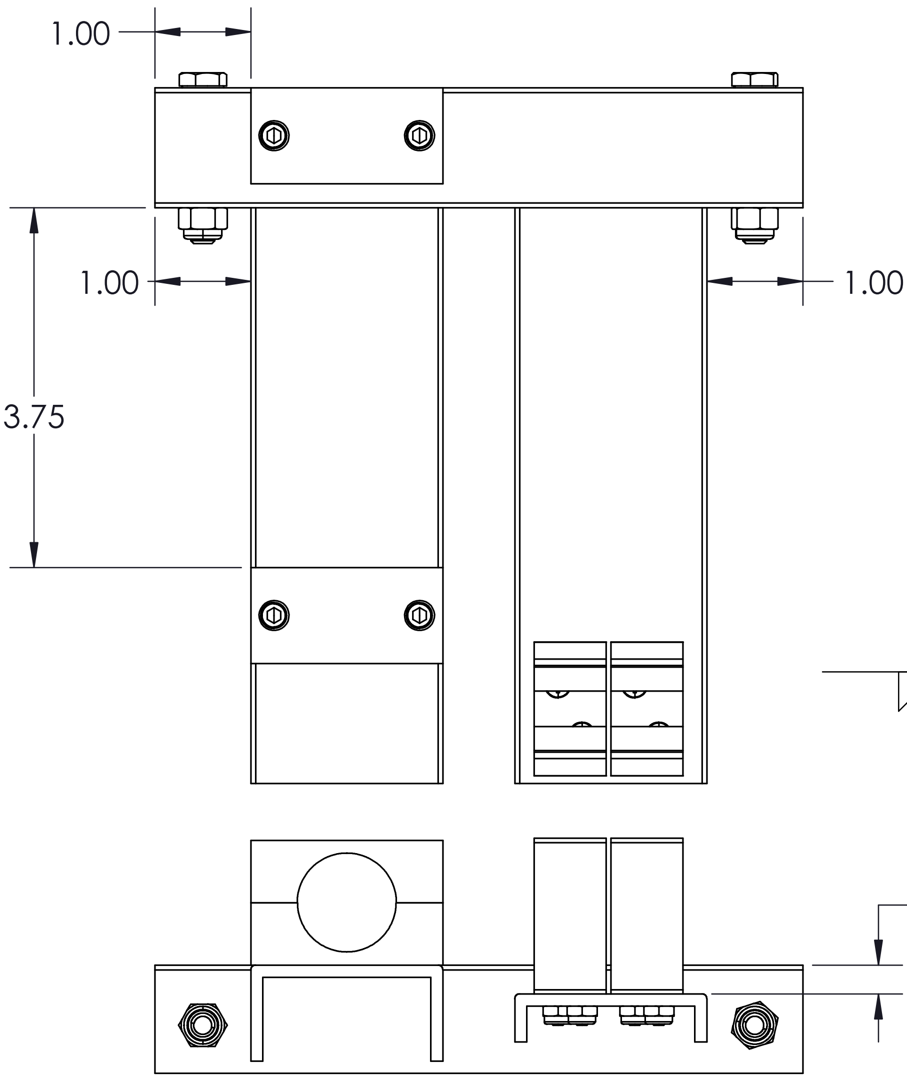
Research Raft

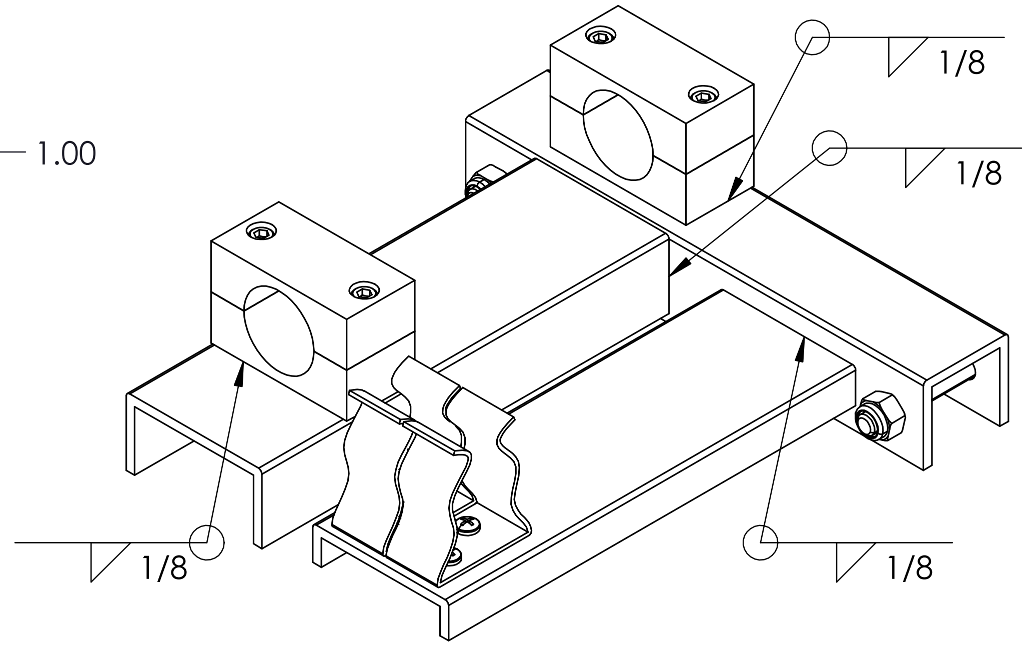
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K. YU	06/07/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 113.30-E | PRT. NO.: 113.30-E

NXT. ASB.: 113.00 | SCALE: 1:2 | SHEET 2 OF 3





NOTES:
USE 5356 FILLER ROD

USE COMPLETED MOTOR ARM TO POSITION
THE HOLDER CLOSEST TO THE CLIP BEFORE WELDING

UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

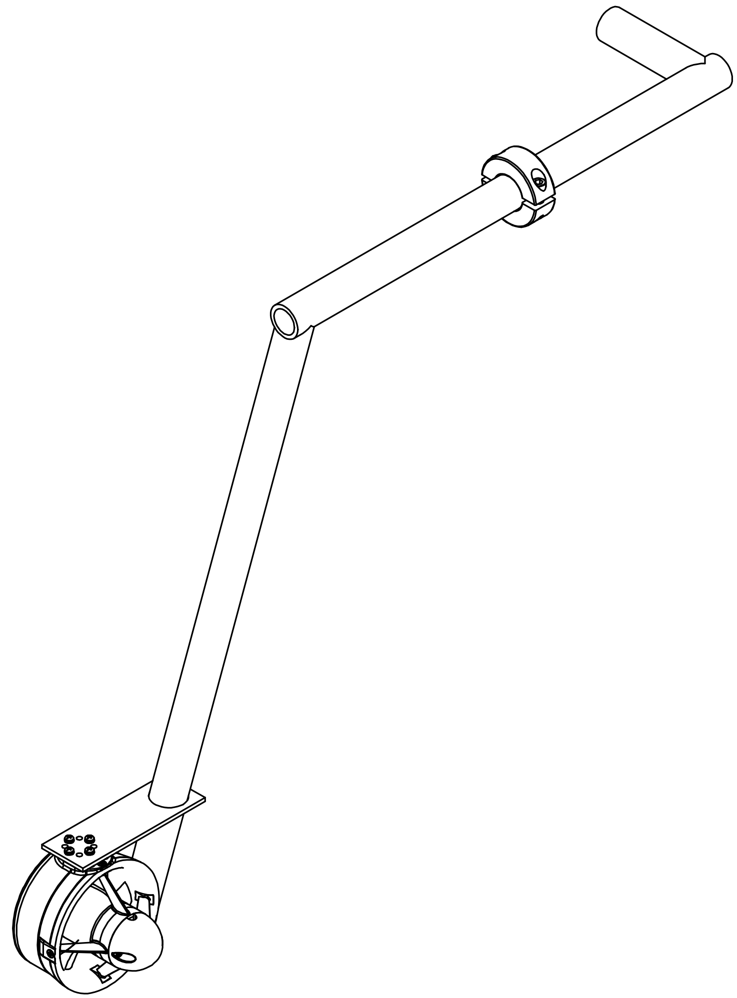
TITLE:

MOTOR MOUNT - RIGHT

CAL POLY SENIOR PROJECT
Research Raft
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K. YU	06/07/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 113.30-W	PRT. NO.: 113.30-W	
NXT. ASB.: 113.00	SCALE: 1:2	SHEET 3 OF 3



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

MOTOR ARM - RIGHT

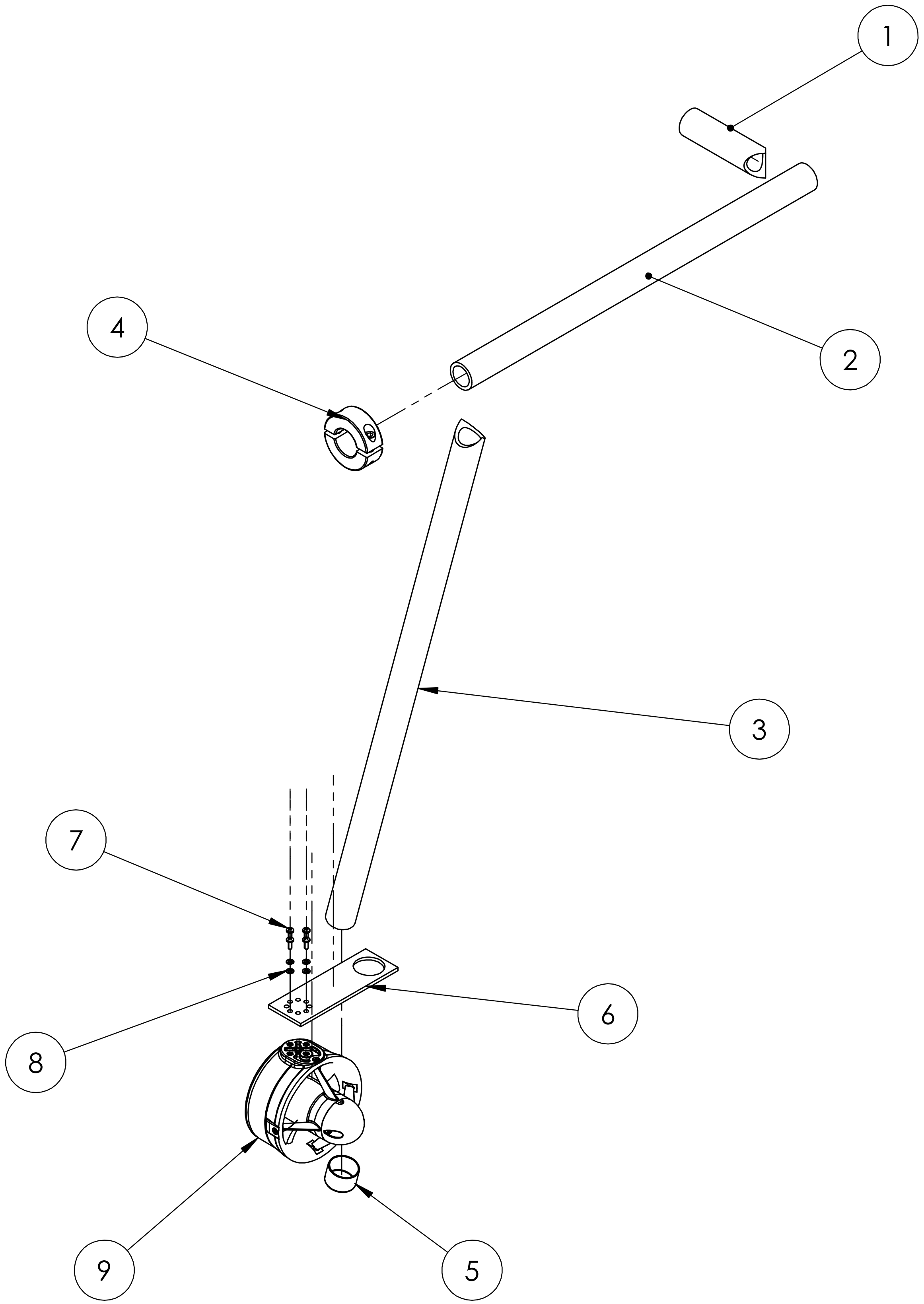
CAL POLY SENIOR PROJECT

Research Raft

SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K. YU	06/07/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 113.40		PRT. NO.: 113.40	
NXT. ASB.: 113.00	SCALE: 1:5	SHEET 1 OF 3	



ITEM NO.	PART NAME	PART NUMBER	QTY.
1	ARM A	112.41	1
2	ARM B	112.42	1
3	ARM C	112.43	1
4	SHAFT COLLAR	112.44	1
5	TUBE END CAP	112.45	1
6	MOTOR ARM PLATE - L	112.46	1
7	THRUSTER SCREW	112.50	4
8	THRUSTER LOCK WASHER	112.60	4
9	THRUSTER	112.70	1

UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

MOTOR ARM - RIGHT

CAL POLY SENIOR PROJECT

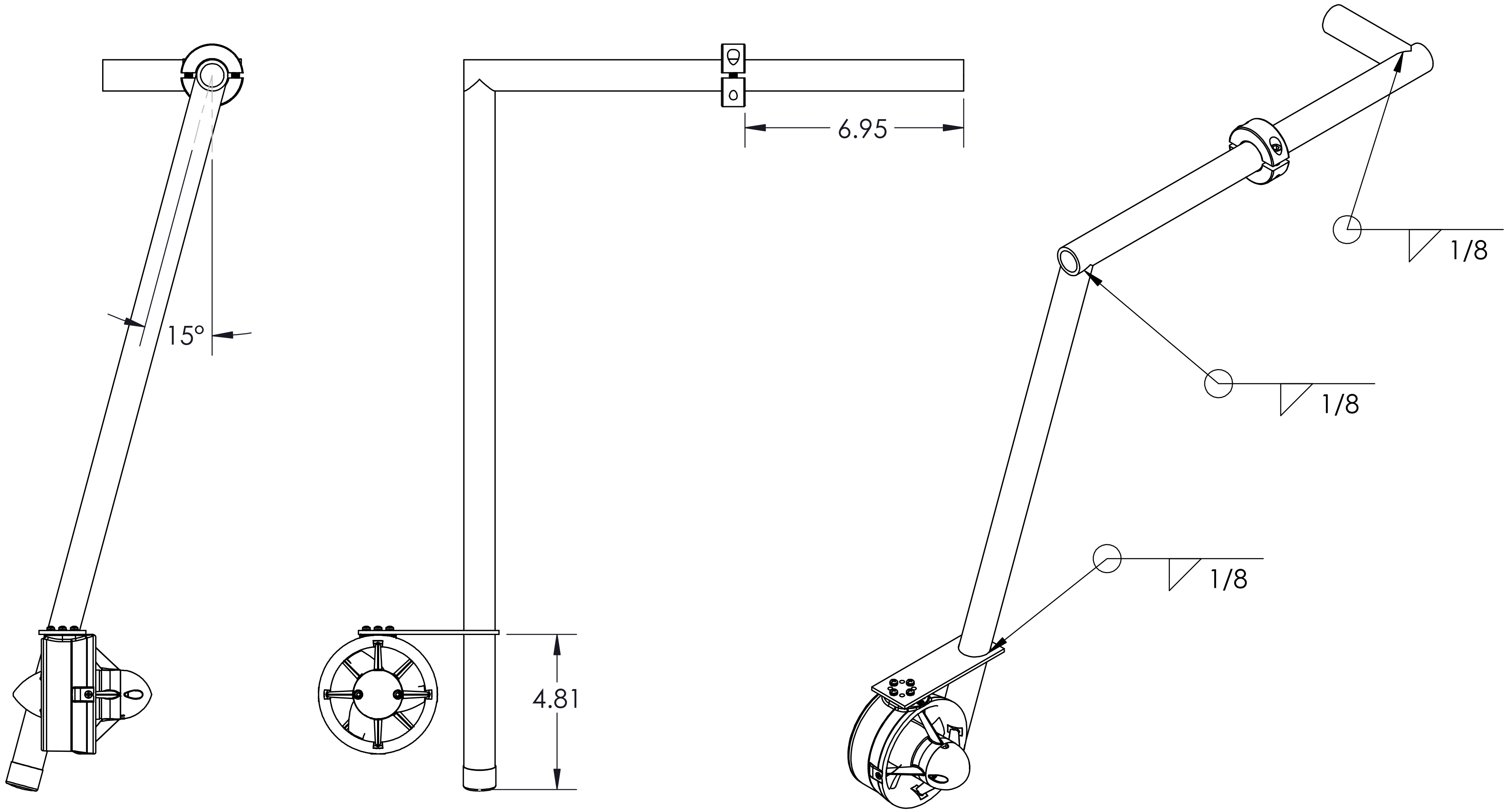
Research Raft

SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K. YU	06/07/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 113.40-E | PRT. NO.: 113.40-E

NXT. ASB.: 113.00 | SCALE: 1:5 | SHEET 2 OF 3



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

MOTOR ARM - RIGHT

CAL POLY SENIOR PROJECT

Research Raft

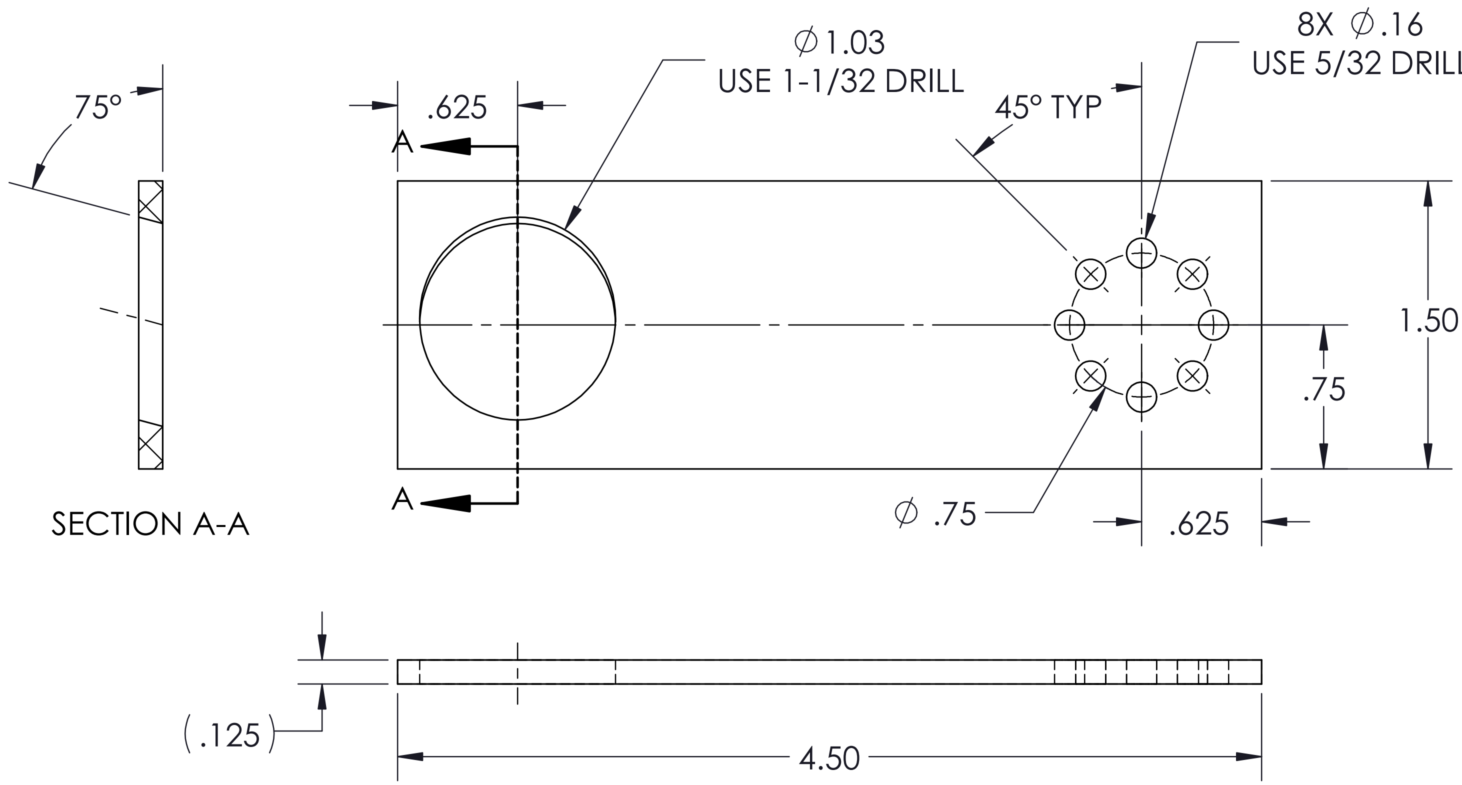
SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K. YU	06/07/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.: 113.40-W	PRT. NO.: 113.40-W	
NXT. ASB.: 113.00	SCALE: 1:5	SHEET 3 OF 3

NOTES:
USE .125 INCH THICK 6061-T6 ALUMINUM SHEET

BREAK SHARP EDGES .01 MAX



UNLESS NOTED OTHERWISE:
ALL DIMS IN INCHES
X.XX ± .02
X.XXX ± .005

TITLE:

ARM PLATE - RIGHT

CAL POLY SENIOR PROJECT

Research Raft

SEPT 2020 - JUNE 2021

	NAME	DATE
DRAWN:	K.YU	06/07/21
CHECKED:	A. FLEMING	06/07/21
APPROVED:	A. FLEMING	06/07/21

DWG. NO.:	113.46	PRT. NO.:	113.46		
NXT. ASB.:	113.40	SCALE:	1:1	SHEET 1 OF 1	

COMPONENT SPECIFICATION SHEET	Assembly	Light Pole	Date
Component 114.20:	Prepared	L. Vickerman	02/22/2021
Flash Head Pole	Checked	L. Vickerman	06/01/2021
Max-Gain Systems Pultruded Fiberglass Tube	Approved	J. Davis	06/06/2021

Visual Reference:

Specification Table:

Tube Parameter	Value
Material	Pultruded Fiberglass
Outer Diameter	1.50”
Inner Diameter	1.25”
Wall Thickness	0.125”
Weight	6.32 oz/ft
Material Properties	**Value**
Flexural Stress	40 ksi
Flexural Modules	1,800 ksi
Tensile Stress	40 ksi
Tensile Modules	2,500 ksi
Compressive Stress	30 ksi

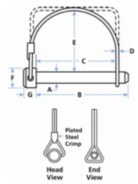
Notes:

∴ The tube comes in a length of 93 inches and will need to be cut down to size.

COMPONENT SPECIFICATION SHEET	Assembly	Light Pole	Date
Component 114.30: Flash Pole Lock Pin 1/4” x 2-3/4” Wire Lock Pin	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

PRODUCT SHEET

1/4" x 2 3/4" Wire Lock Pin - WIRE-2SQ



PRODUCT DETAILS

Basic Shank Diameter [in]	1/4
Size [in]	1/4 x 2-3/4
Pin Diameter [in]	0.243 to 0.248
Pin Length - B [in]	2.750
Effective Length - C [in]	2.500
Wire Diameter - D [in]	0.091
Loop Clearance - E [in]	1.562
Head Diameter - F [in]	0.485
Head Height - G [in]	0.235
Material	Zinc Plated Steel
Finish	Zinc Plated
Approximate Weight/Pounds per 100 Pieces [lb]	8.18
Wire Loop Shape	Square

Need pricing or samples? Just send this sheet to mail@pivotpins.com. We're happy to help!

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PINS > CABLES > SOLUTIONS
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Hustisford, WI 53034

(800) 222-2231
(920) 349-3251 Int.
(920) 349-3253 Fax
mail@pivotpins.com

COMPONENT SPECIFICATION SHEET	Assembly	Battery	Date
Component 115.10:	Prepared	L. Vickerman	02/22/2021
Lithionics Battery	Checked	L. Vickerman	06/01/2021
Model: GTX12V315A-E2107-CS200	Approved	J. Davis	06/06/2021

LITHIONICS BATTERY®

LITHIUM-ION IRON PHOSPHATE BATTERY SYSTEMS

MODEL NUMBER:
GTX12V315A-E2107-CS200

Designed with Bluetooth® Wireless Monitoring, Internal Heater Kit, Aluminum Alloy Enclosure

INTERNAL BMS VERSION

Item		Description
Model		GTX12V315A-E2107-CS200
Nominal Voltage		12.8V
Nominal Capacity		315Ah
Nominal Watt Hours		4032Wh
Internal Resistance		<3mΩ
Charge		
Charging temperature range		32F/0C to 131F/55C
Charge voltage		14.4V
Recommended float charge voltage(for standby use)		13.4-13.6V
Recommended max charge current*		150A
Allowed max charge current*		250A
Discharge		
Discharging temperature range		-4F/-20C to 131F/55C
Operating Voltage Range		11.6-13.4V
Recommended max discharge current*		200A
Max discharge current*		250A
Pulse discharge current (1 second)		1200A
Discharge cut-off voltage		NeverDie® Power Reserve @ 12.0V Low-Voltage Cut-Off @11.6V
Mechanical		
Dimensions		Length 20.3"
		Width 6.4"
		Height 10.0"
Mounting Orientation		Upright position only (terminals up)
Weight		Approx. 68lbs (30.8kg)
Terminal Bolt Size		M8-1.25x14mm
Storage		
Storage Temperature & Humidity Range	< 1 Month	-4~95°F (-20~35°C), 45~75%RH
	< 3 Months	14~86°F (-10~30°C), 45~75%RH
	Recommended storage	59~95°F (15~35°C). 45%RH~75%RH
Long Term Storage	If the battery needs to be stored for > 3 months the voltage should be 13.2V (50%SOC), and stored at the recommended storage specifications shown above. Additionally, the battery needs at least one charge & discharge cycle every six months.	
Self-discharge rate	Residual capacity	≤3% per month; ≤15% per year
	Reversible capacity	≤1.5%per month; ≤8% per year

30% Smaller than 3 x 100Ah Group31 Batteries, with Extra 15Ah to Spare

INTERNAL NEVERDIE® BMS FEATURES

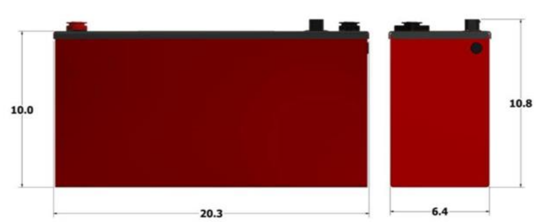
- NeverDie® Power Reserve (Spare Fuel) for Hotel Loads and Engine Cranking
- Over-Charge, Over-Discharge and Short-Circuit Protection (LVC, HVC, SCC)
- Low/High Temperature Charge/Discharge Protection
- Internal Heating Kit: Permits Charging as low as -20C/-4F
- Pushbutton On/Off switch for Safety and Storage
- Battery Gauge and Status Codes for Health Monitoring
- Bluetooth wireless telemetry with Lithionics Battery iOS and Android app
- CANbus telemetry in the RVIA RV-C format (AMPSEAL8)
- An alternator Field Control Circuit (FCC) (AMPSEAL8)
- Remote LED illuminated On/Off Power switch (AMPSEAL8)
- Up to 250A continuous charge/discharge current

ENERGY

315 AMP HOURS

PULSE AMPS: 1200 (1 SEC)

4032 WATT-HOURS



COMPONENT SPECIFICATION SHEET	Assembly	Battery	Date
Component 115.20: NRS 1" HD Tie-Down Straps Length: 6 feet	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:

Specification Table:

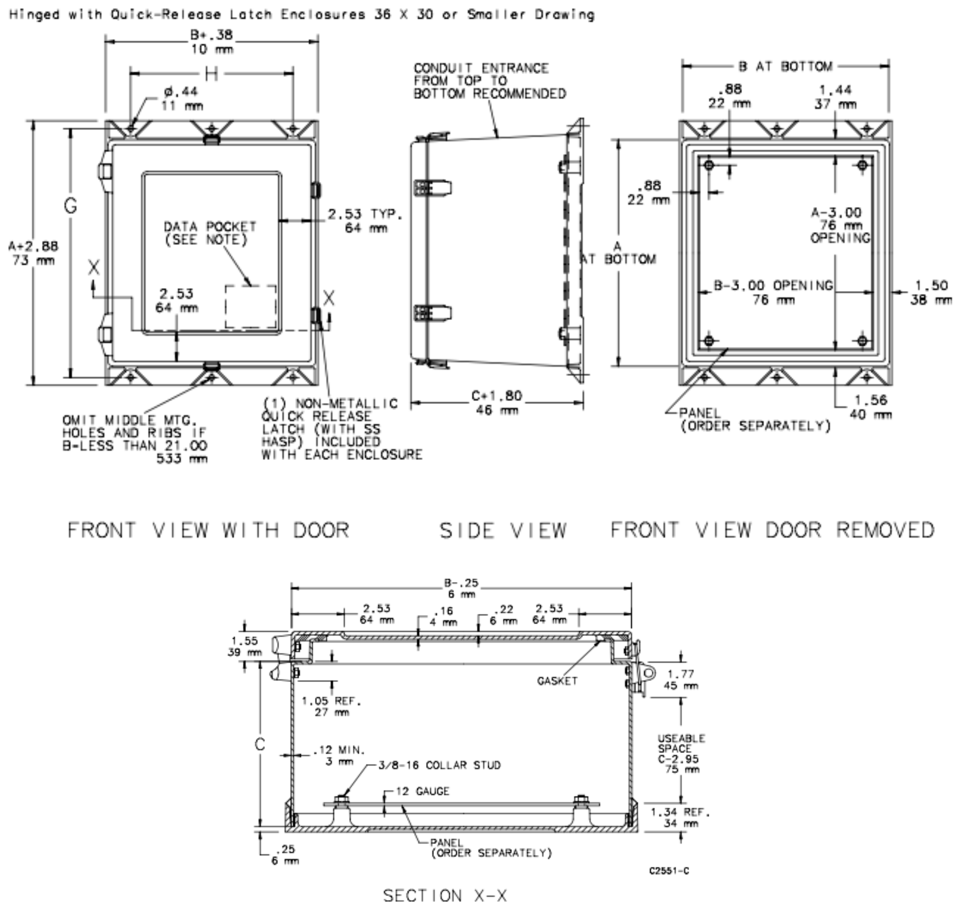
Specification	Measurement / Quantity
Strap Length	6 feet
Minimum Breaking Strength	1,500 pounds
Working Load Limit	500 pounds
Material	UV-protected polypropylene webbing

Notes:

∴ Straps are sold in pairs.
∴ Webbing can be cut down to desired length if tag end is too long.
∴ NRS product 60027.01.104

COMPONENT SPECIFICATION SHEET	Assembly	Payload Box	Date
Component 116.10: Hoffman Fiberglass Hinge Cover Model: A20H1612GQRLP	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:



Specification Table:

Parameter	Value
A x B x C	20.19 x 16.25 x 12.00
Panel	A20P16
Panel Size	17.00 x 13.00
Mtg G x H	21.81 x 10.00
No. of Latches	4
Material	Fiberglass
Rating	NEMA 4X

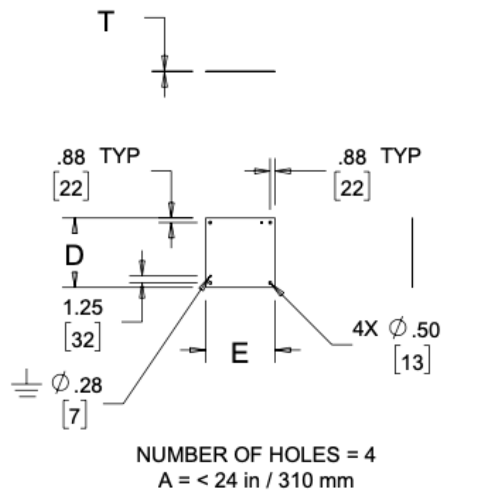
Notes:

∴ The selected model only has two mounting holes.

∴ Panel is ordered separately.

COMPONENT SPECIFICATION SHEET	Assembly	Payload Box	Date
Component 116.20: Hoffman Aluminum Panel Model: A20P16AL	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:



Specification Table:

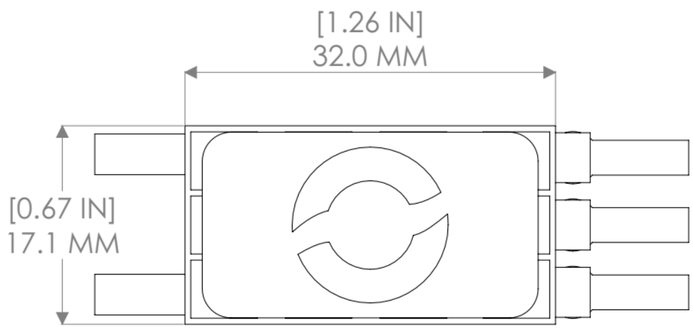
Parameter	Value
Material	Aluminum
Panel Size D x E	17.00 in x 13.00 in
Thickness	0.10 in
Number of Holes	4

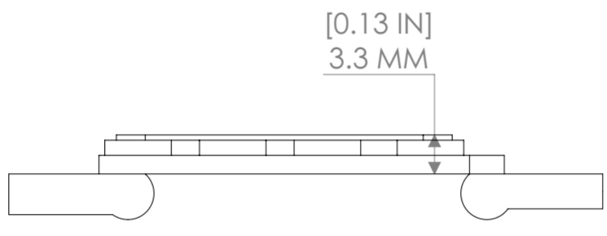
Notes:

∴ Panels can be ordered with perforation or different material if needed.

COMPONENT SPECIFICATION SHEET	Assembly	Payload Box	Date
Component 116.30:	Prepared	L. Vickerman	02/22/2021
Blue Robotics Basic ESC	Checked	L. Vickerman	06/01/2021
SKU: BESC30-R3	Approved	J. Davis	06/06/2021

Visual Reference:





Specification Table:

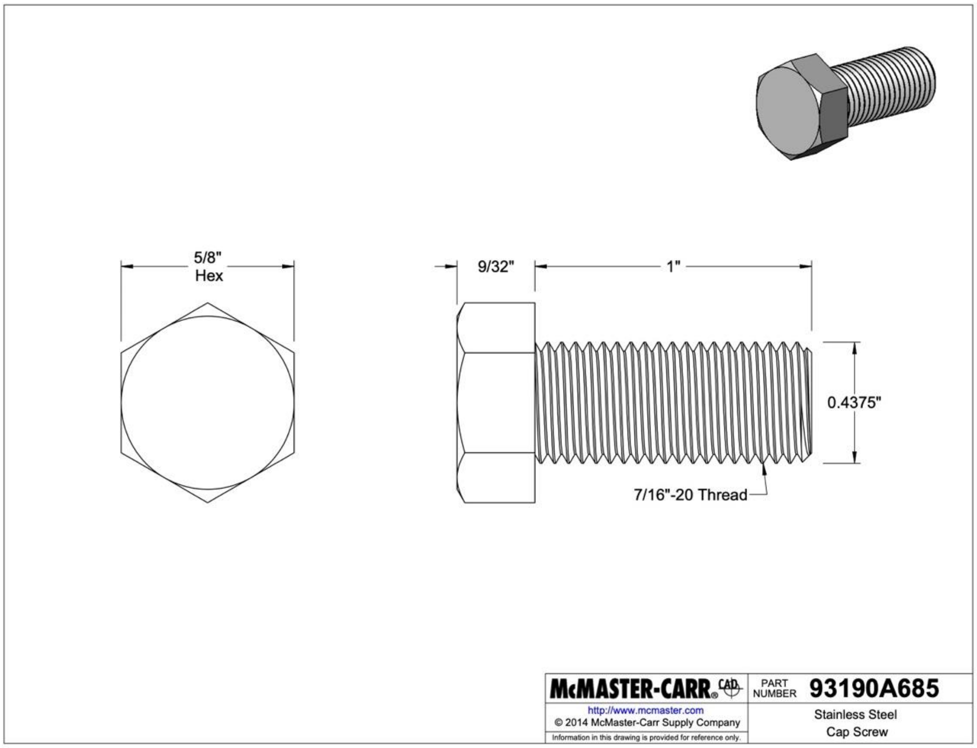
Parameter	Value
Voltage	7-26 volts (2-6S)
Max Current (Constant)	30 amps (depending on cooling)
Weight	0.036 lb
Power Connectors	Spade terminals for No. 6 screw
Motor Connectors	Tinned wire ends
Signal Connectors	3-pin servo connector (0.1" pitch) (ground, black, signal)
Signal Voltage	3.3-5 volts
Max Update Rate	400 Hz
Stopped	1500 microseconds
Max Forward	1900 microseconds
Max Reverse	1100 microseconds
Signal Deadband	+/- 25 microseconds (centered around 1500 microseconds)

Notes:

∴ Guides and user manual can be found on the Blue Robotics website.

COMPONENT SPECIFICATION SHEET	Assembly	Payload Box	Date
Component 116.40: Payload Box Mounting Bolt 7/16”-20 x 1” Hex Head Screw	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:



Specification Table:

Parameter	Value
Diameter / Thread Size	7/16”-20
Finish	n/a
Grade	2A
Length	1”
Material	Stainless Steel
Thread	Fine
Thread Type	Full Thread
Type	Hex Cap Screw
Wrench Size	5/8”
Product Weight	n/a
McMaster Carr SKU	93190A685

Notes:

COMPONENT SPECIFICATION SHEET	Assembly	Payload Box	Date
Component 116.50: Payload Box Mounting Nut 7/16”-20 Grade C Zinc Finish Lock Nut	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:

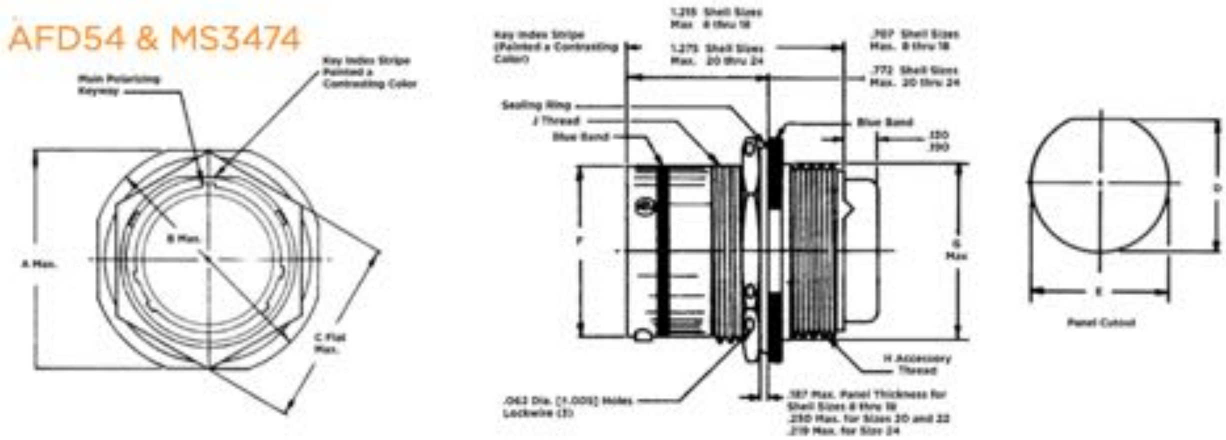
Specification Table:

Parameter	Value
Diameter / Thread Size	7/16”-20
Finish	Zinc
Grade	C
Material	Steel
Thickness	0.463”
Thread	Fine
Type	Top Lock Nut
Wrench Size	5/8”
Product Weight	0.025 lb
Fastenal SKU	37306

Notes:

COMPONENT SPECIFICATION SHEET	Assembly	Payload Box	Date
Component 116.60:	Prepared	L. Vickerman	06/01/2021
Through Box Connector	Checked	J. Davis	06/06/2021
Mouser MS3474L14-4P Connector	Approved	J. Davis	06/06/2021

Visual Reference:



AFD54 & MS3474

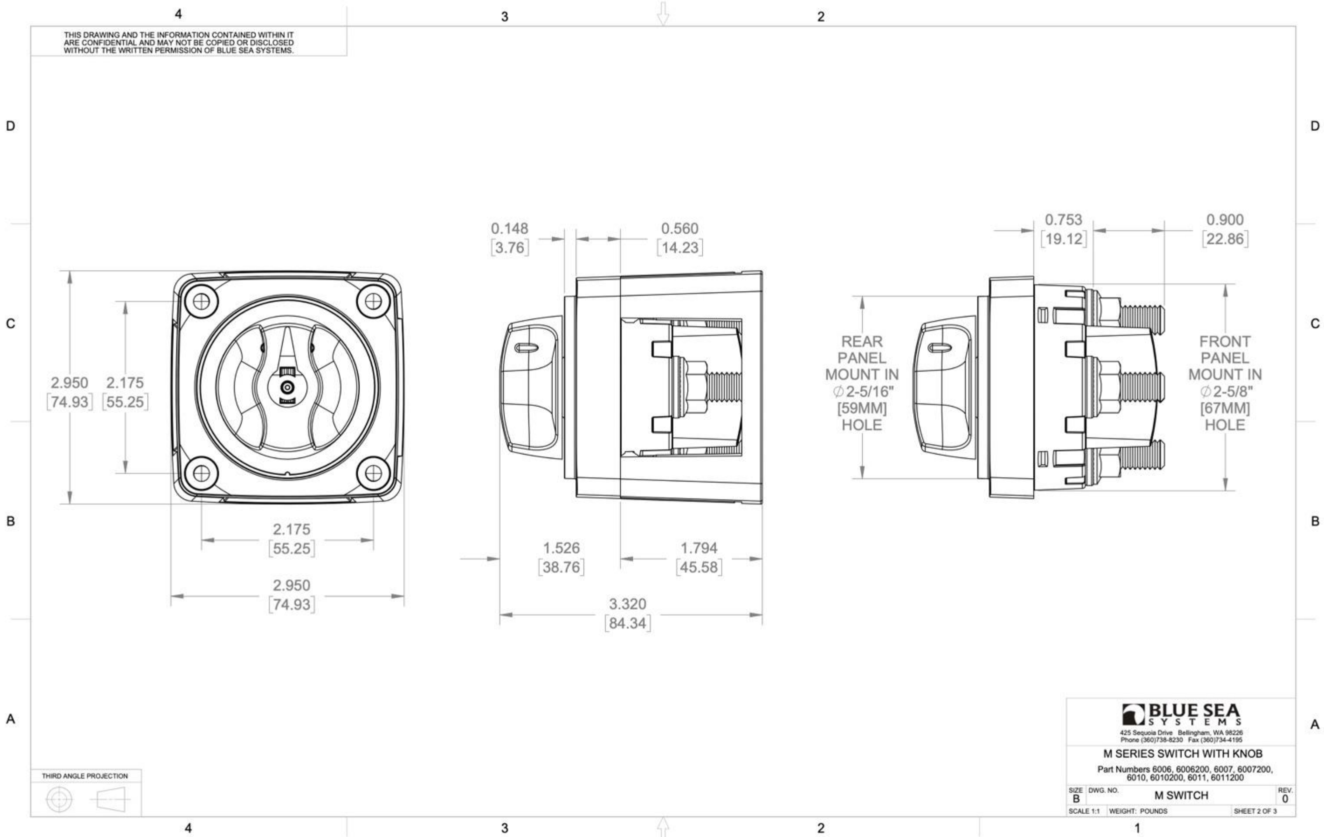
Size	A		B		C ± .005		D ± .005		F ± .000/-.005		F ± .015		G		H Thread	J Thread
	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm		
8	0.954	24.232	1.078	27.381	0.766	19.456	0.536	13.614	0.572	14.529	0.473	12.014	0.615	15.621	1/2 - 20 UNF	9/16 - 24 UNEF
10	1.078	27.376	1.203	30.556	0.892	22.657	0.661	16.789	0.697	17.704	0.590	14.986	0.734	18.644	5/8 - 24 UNEF	11/16 - 24 UNEF
12	1.266	32.156	1.391	35.331	1.079	27.407	0.824	20.930	0.895	22.733	0.750	19.050	0.858	21.793	3/4 - 20 UNEF	7/8 - 20 UNEF
14	1.391	35.331	1.516	38.506	1.205	30.607	0.948	24.079	1.010	25.654	0.875	22.225	0.984	24.994	7/8 - 20 UNEF	1 - 20 UNEF
16	1.516	38.506	1.641	41.681	1.329	33.757	1.072	27.229	1.135	28.829	1.000	25.400	1.112	28.245	1 - 20 UNEF	1 1/8 - 18 UNEF
18	1.641	41.681	1.766	44.856	1.455	36.957	1.197	30.404	1.260	32.004	1.125	28.575	1.218	30.937	1 1/16 - 18 UNEF	1 1/4 - 18 UNEF
20	1.828	46.431	1.954	49.632	1.579	40.107	1.322	33.579	1.384	35.154	1.250	31.750	1.345	34.163	1 3/16 - 18 UNEF	1 3/8 - 18 UNEF
22	1.954	49.632	2.078	52.781	1.705	43.307	1.447	36.754	1.510	38.354	1.375	34.925	1.468	37.287	1 5/16 - 18 UNEF	1 1/2 - 18 UNEF
24	2.078	52.781	2.203	55.956	1.829	46.457	1.572	39.929	1.635	41.529	1.500	38.100	1.593	40.462	1 7/16 - 18 UNEF	1 5/8 - 18 UNEF

Notes:

∴ Reference manufacturer’s website and full specification sheet for further details.

COMPONENT SPECIFICATION SHEET	Assembly	Electronics	Date
Component 116.71:	Prepared	L. Vickerman	06/01/2021
Main Power Switch	Checked	J. Davis	06/06/2021
Blue Sea Systems On-Off Battery Switch	Approved	J. Davis	06/06/2021

Visual Reference:



Specification Table:

Parameter	Value
Switch Type	Single Circuit On-Off
Switch Positions	2
Maximum Voltage	48V DC
Continuous Rating	300 A
Stud Size	3/8”
Battery Inputs	1

Notes:

COMPONENT SPECIFICATION SHEET	Assembly	Electronics	Date
Component 116.72:	Prepared	L. Vickerman	06/01/2021
Main Power Fuse	Checked	J. Davis	06/06/2021
Littelfuse 142.5631.6102 Bolt-Down Fuse	Approved	J. Davis	06/06/2021

Visual Reference:

High Current Fuses

Littelfuse
Expertise Applied | Answers Delivered

BF1 Fuses Rated 58V

This BF1 fuse is rated at 58V and offers a bolt-on fuse for high current wiring protection. Current rating 30A - 200A; with transparent housing material for easy detection of blown fuses.

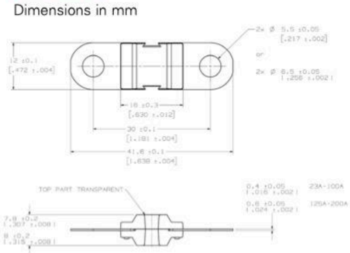
Specifications

Operating temperature:	-40 to 125 degrees C
Housing Material:	PET-GF30
Clear Housing Material:	PES
Terminals:	Copper alloy, gal. Sn 2 x M5 or M6 bolts, distance 30 mm
Mounting Torque M5:	4.5 Nm +/- 1Nm
Mounting Torque M6:	6.0 Nm +/- 1Nm
Interrupting Rating:	1000A @ 58 VDC
Complies with:	ISO 8820-5, UL 248 Special Purpose Fuses

c UL us RoHS

Dimensions

Dimensions in mm



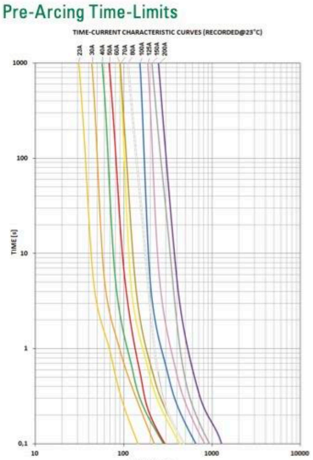
Ordering Information

Part Number	Package Size	Bolt Size	Bolt Hole Qty
142.5631.xxx2	500	M5	2
142.7010.xxx2	500	M6	2
142.0020.xxx2	500	N/A	0

Time-Current Characteristics

% of Rating	Opening Time Min / Max (s)	
	30-150A Fuses	200A Short Circuit Protectors
75	– / –	360,000 s / –
100	360,000 s / –	– / –
110	14,400 s / –	– / –
150	90 s / 3,600 s	– / –
200	3 s / 100 s	1 s / 15 s
300	0.300 s / 3 s	– / –
350	– / –	0.300 s / 5 s
500	0.100 s / 1 s	– / –
600	– / –	0.100 s / 1 s

Pre-Arcing Time-Limits



30 A - 150 A: FI = 1.25
(max. operating current:0.8 x I_{rat} at 23°C)
200 A: FI = 2.00
(max.operating current: 0.5 x I_{rat} at 23°C)

Ratings

Part Number M5	Part Number M6	Current Rating (A)	Housing Material Color	Typ. Voltage Drop (mV)	Cold Resistance (mΩ)	I^2t (A^2s)
142.5631.5302[1]	142.70xx.5302[1]	30		105	2.70	5,100
142.5631.5402	142.70xx.5402	40		90	1.56	6,800
142.5631.5502	142.70xx.5502	50		80	1.03	6,900
142.5631.5602	142.70xx.5602	60		75	0.75	16,200
142.5631.5702	142.70xx.5702	70		70	0.64	22,000
142.5631.5802	142.70xx.5802	80		70	0.55	25,600
142.5631.6102	142.70xx.6002	100		70	0.44	42,500
142.5631.6122	142.70xx.6122	125		70	0.34	62,500
142.5631.6152	142.70xx.6152	150		70	0.29	83,400
142.5631.6202[2]	142.70xx.6202	200		70	0.24	126,000

Note 1: Not UL rated   Note 2: Short Circuit Protector only

Derating

Individual derating curves by rating can be ordered through your Littelfuse contact person.

Notes:

COMPONENT SPECIFICATION SHEET	Assembly	Electronics	Date
Component 116.73:	Prepared	L. Vickerman	06/01/2021
Fuse Holder	Checked	J. Davis	06/06/2021
Littlefuse 04981038HXFC Fuse Holder	Approved	J. Davis	06/06/2021

Visual Reference:

Commercial Vehicle Product Datasheet

Littelfuse
Expertise Applied | Answers Delivered

FLEX MIDI® FUSE HOLDER

32V DC • 200A • In-Line • Interlocking for Multi-Pole Fuse Holder Assemblies

Specifications Overview

Max Voltage Rating:	32V DC
Max Current Rating:	200A
Wire Size:	8 mm² to 35 mm²
Stud Torque:	3-5.0 Nm (M5 Threads)
Mounting Torque:	5 Nm (M4 Bolts & Washers)
Operating Temp:	-40 to +125 °C
Flammability Rating:	UL94 V-0
Dimensions:	78.4 x 29.9 x 38.3 mm

Description

The FLEX MIDI® fuse holder is used with the MIDI® style bolt-down fuse, which is available up to 200A. This holder offers a flexible cover, which allows cable entry from virtually any direction, large wire size, and ring terminal stack up. Slots on the base allow holder to be mounted with tie wraps. Dovetail features allow you to interlock multiple FLEX MIDI® fuse holders together for a high power distribution block. Bus bars are available for multiple holder applications.

Features and Benefits

- Flexible cover allows for cable entry from virtually any direction allowing for easier installation.
- Dovetail features allow you to interlock multiple Flex holders together to create a high power distribution block. Combine with the Flex-MEGA® fuse holder for a high and low amperage solution.
- Slots are molded into the base that allow the holder to be securely mounted with tie-wraps.
- Zinc plated steel hardware and tin-plated 100% pure copper optimize long-term corrosion protection.

Recommended Fuses

- Littelfuse series: MIDI® 498 Series, BF1 Series
- Also accepts competitive cross-reference equivalent fuses

Web Resources

Download 2D outline and additional technical resources at:
littelfuse.com/flex-midi

Ordering Information

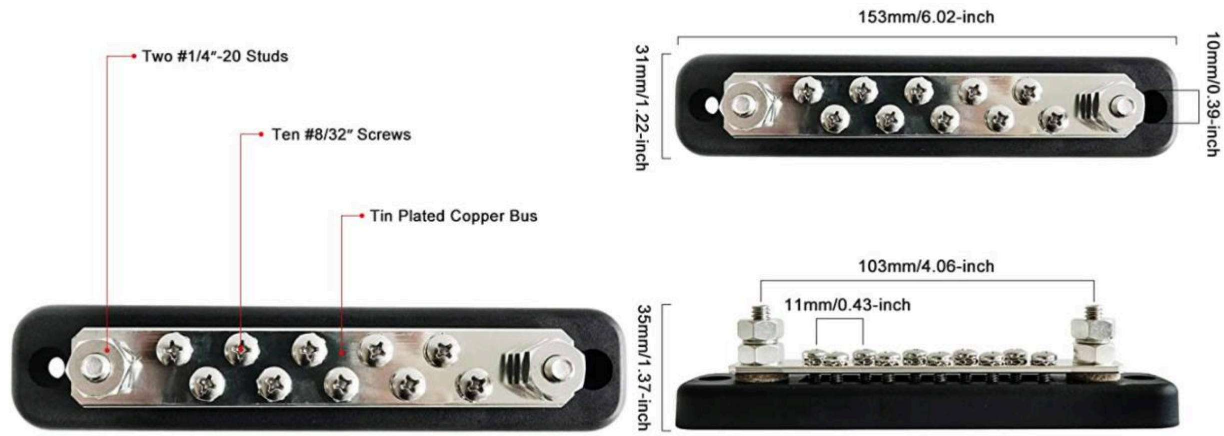
BLUK PART NUMBER	BLISTER PART NUMBER	DESCRIPTION	MATERIAL (STUDS AND HARDWARE)
04981038HXFC**	04981038-BP	Complete Assembly	Zinc-Plated Steel
04982001ZXFC*	—	2-Pole Complete Assembly (2 holders, 2 position bus bar; fuses not included)	Zinc-Plated Steel
882-267-002*	—	2 Position Bus Bar	Tin Plated Copper
882-267-003*	—	3 Position Bus Bar	Tin Plated Copper
882-267-004*	—	4 Position Bus Bar	Tin Plated Copper
882-267-005*	—	5 Position Bus Bar	Tin Plated Copper

**Special Order*
*** Retail Packaging Available*

Notes:

COMPONENT SPECIFICATION SHEET	Assembly	Electronics	Date
Component 116.74: Bus Bar 10 Terminal Bus Bar for Boat/Marine	Prepared	L. Vickerman	06/01/2021
	Checked	J. Davis	06/06/2021
	Approved	J. Davis	06/06/2021

Visual Reference:



Specification Table:

Parameter	Value
Number of Ports	10
Current Rating	150 A
Input Voltage	12 V
Material	Tin Plated Copper

Notes:

COMPONENT SPECIFICATION SHEET	Assembly	Electronics	Date
Component 116.75: Motor Cable Extension Blue Robotics Thruster Cable 16 AWG	Prepared	L. Vickerman	06/01/2021
	Checked	J. Davis	06/06/2021
	Approved	J. Davis	06/06/2021

Visual Reference:

Specification Table:

Parameter	Value
Construction	3-conductors, tape wrap, jacket
Outer Jacket	Pressure-extruded polyurethane
Conductor Gage	16 AWG
Diameter	0.25”

Notes:

COMPONENT SPECIFICATION SHEET	Assembly	Electronics	Date
Component 116.76: ESC-Motor Cable Terminal Adels Contact 121203 Terminal Block	Prepared	L. Vickerman	06/01/2021
	Checked	J. Davis	06/06/2021
	Approved	J. Davis	06/06/2021

Visual Reference:

ADELS contact

Screw Terminal Blocks

230/ 3

terminal block, 3 pole, insulating material: PA 6, cross-section rating: 2.5 mm², pin spacing: 8.00 mm, mounting hole diameter: 2.8 mm, fixing: screw, voltage rating: 450 V, current rating: 24.0 A

Order Info

reference number (ref. no.)	121203
PU	2,000
EAN	4028012105175

Type

type	terminal block
number of poles	3 pole
clamping units per pole	1
colour	natural
cross-section rating	2.5 mm²
connection type	screw

Technical Data

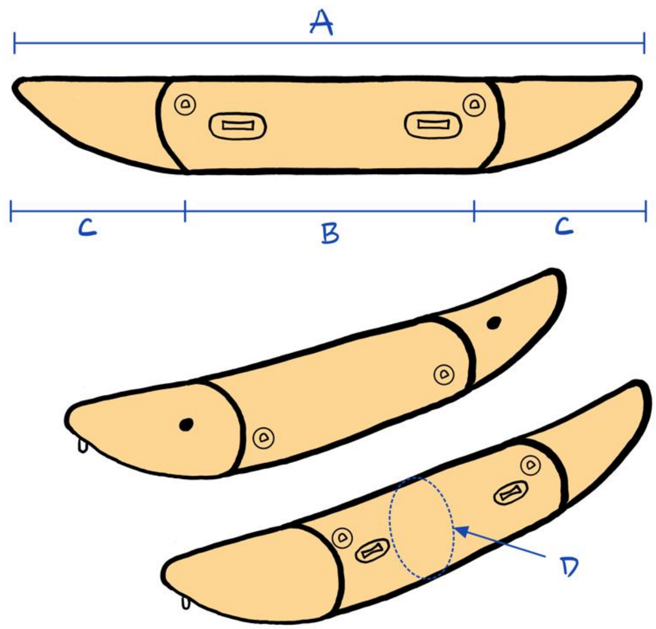
voltage rating	450 V
current rating	24.0 A
insulating material	PA 6
contact material	brass
core cross-section min.	0.5 mm²
core cross-section max.	4.0 mm²
flammability rating	V-2
max. Ambient Temperature Operation	85 °C
type of conductor solid	yes
type of conductor flexible	yes
type of conductor stranded	yes
stripping length	5.0-5.5 mm
Assembly Contact Screw	0.8x4.0 / ↻ 0.5 Nm
mounting hole diameter	2.8 mm
pin spacing	8.00 mm
fixing	screw

01/06/2021

Notes:

COMPONENT SPECIFICATION SHEET	Assembly	Pontoon	Date
Component 121.00: Custom sized pontoons manufactured by Maravia.	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:



Specification Table:

Specification	Measurement / Quantity
A (Overall Length)	9 feet
B (Straight Section)	48 inches
C (Optional Bow/Stern rise)	30 inches
D (Tube Diameter)	16 inches
Air Chambers	2 per pontoon
D-Ring Attachment Points	8 per pontoon
Lift Handles	2 per pontoon
Material	PVC shell encapsulated in urethane

Notes:

∴ The specified pontoons are not a standard size and must be custom ordered.
∴ The minimum amount of air chambers used is two, but more will not compromise the design.
∴ The specified pontoons do not have any bow/stern rise. Bow and stern rise is optional and dependent on manufacture’s capabilities.

COMPONENT SPECIFICATION SHEET	Assembly	Pontoon	Date
Component 122.00: NRS 1" HD Tie-Down Straps Length: 2 feet	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:

Specification Table:

Specification	Measurement / Quantity
Strap Length	2 feet
Minimum Breaking Strength	1,500 pounds
Working Load Limit	500 pounds
Material	UV-protected polypropylene webbing

Notes:

∴ Straps are sold in pairs.
∴ Webbing can be cut down to desired length if tag end is too long.
∴ NRS product 60027.01.101

COMPONENT SPECIFICATION SHEET	Assembly	Pontoon	Date
Component 123.00: NRS 1” HD Tie-Down Straps Length: 3 feet	Prepared	L. Vickerman	02/22/2021
	Checked	L. Vickerman	06/01/2021
	Approved	J. Davis	06/06/2021

Visual Reference:

Specification Table:

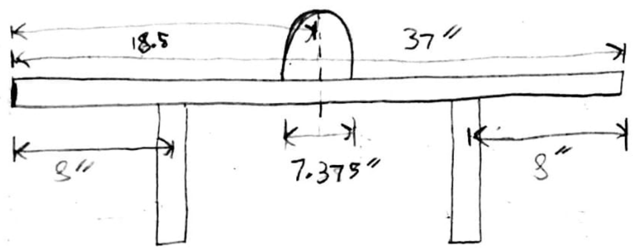
Specification	Measurement / Quantity
Strap Length	3 feet
Minimum Breaking Strength	1,500 pounds
Working Load Limit	500 pounds
Material	UV-protected polypropylene webbing

Notes:

- ∴ Straps are sold in pairs.
- ∴ Webbing can be cut down to desired length if tag end is too long.
- ∴ NRS product 60027.01.102

N. Appendix N: Frame Hand Calculations

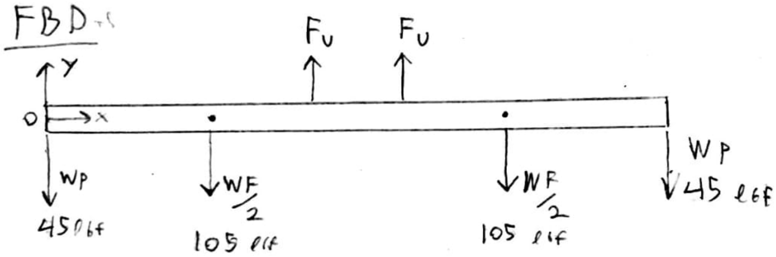
Main Lift Point Member- Hand calcs



$W_{pontoon} = 45$ lbs

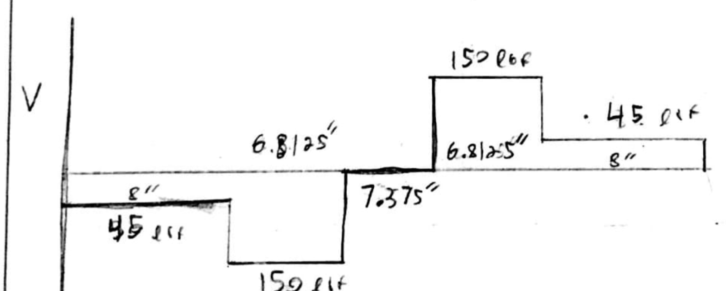
$W_{Frame} = 210$ lbs

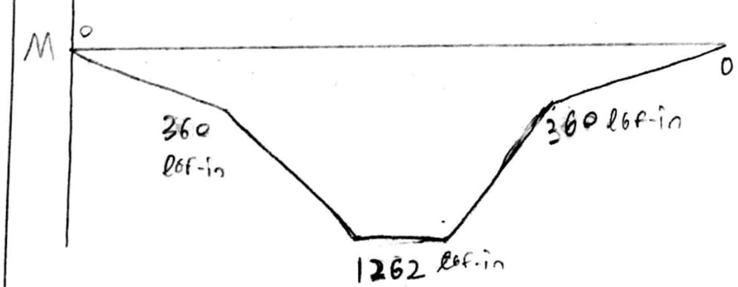
Assume weight of frame/payload goes through the supports
Assume weight of pontoons goes through Ends
Assume pinned connections at supports



$\Sigma F_y = -2wp - wf + 2F_U = 0$

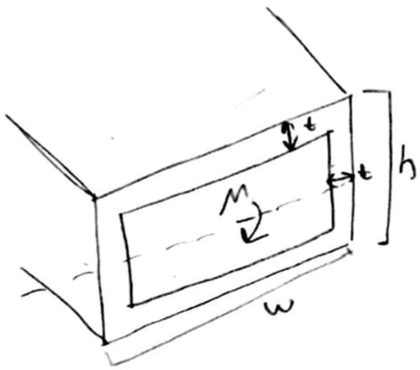
$F_U = \frac{2wp + wf}{2} = \frac{60\,lbf + 240\,lbf}{2} = 150\,lbf$





Max Moment

1262 lbf-in



$h = 1 in$

$\omega = 1.5 in$ $\qquad I = 0.08105 in^4$

$t = .125 in$

$M = 1261 \, lbf\text{-}in$

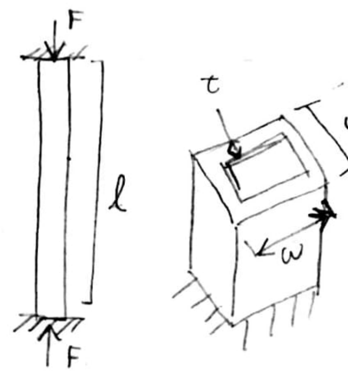
$$\sigma_x = \pm \frac{My}{I} = \frac{1261 \, lbf \, in \, (.5 in)}{0.08105 in^4}$$

$\sigma_x = 7780 \ psi$

$S_y \ AL \ 6061\text{-}T6 = 40 ksi$

$$n = \frac{S_y}{\sigma x} = \frac{40000 \ psi}{7780 \ psi} = \boxed{5.1 \text{ Safety factor - Bending}}$$

VERTICAL MEMBER HAND - CALCS



$\omega = 1$
$t = .0625\text{in}$ (1/16 in)
$L = 8''$

$A = \omega^2 - (\omega - 2t)^2 = 1^2 - (1 - .125)^2 = 0.2344\ \text{in}^2$

$I = 0.0345\ \text{in}^4$ (online calculator)

$k = 0.384$ (online calculator, Radius of Gyration)

l/k to determine Short Beam vs Euler

$l/k = \dfrac{8\ \text{in}}{.384\text{in}} = 20.8 << 40$ ∴ compression strength is sufficient

Also a "Fixed - Fixed" Constrained beam

$\dfrac{S_y}{n} = \sigma_{allowable} = \dfrac{F_{allowable}}{A}$

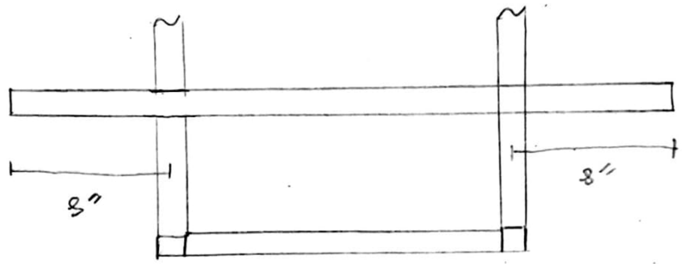
For AL 6061 $\sigma_y = 40\text{ksi}$ $n = 1.25$

$F_{allowable} = \dfrac{40\text{ksi}\ (.2344\text{in}^2)}{1.25} = 7500\ lbf$

OR 25 X 300 lb RAFTS STACKING AT WORST

AT BEST, Force IS DIVIDED AMONG 4 MEMBERS

MAIN LATERAL MEMBER - HAND CALCS



Assume Fixed end condition @ welded support joint
- Cantilever beam

LOADING

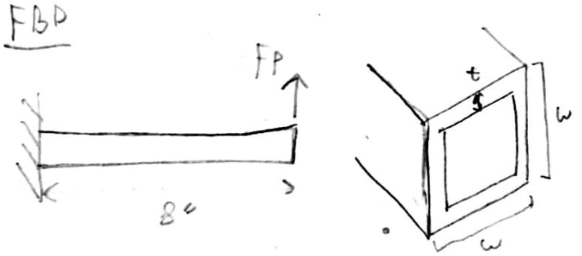
1 Pontoon takes 1/2 total weight

2 rafts stacked w/ lower pontoons Inflated

$w_{total} = 300\,n$ lbf n = # stacked

Assume loading only on 1 member, In reality there are 3 Including the Lift point, distributed unequally

FBD



t = .125 in

w = 1 in

$I = .05697\ in^4$

$A = 0.4375\ in^2$

$\sigma_x = \frac{My}{I} = \frac{2in\ F_P\ (.5)}{.05697\ in^4}$ $\sigma_{allowable} = \frac{\sigma_{yield}}{n} = \frac{40\ ksi}{1.25}$

$\sigma_x = 70.2\ F_P \frac{1}{in^2} = \sigma_{allowable} = 32000 \frac{lbf}{in^2}$

$\boxed{F_{P\,Allowable} = 456\ lbf}$

AT WORST, FRAME CAN SUPPORT 3 HIGH STACKING
When bottom pontoons are inflated.

O. Appendix O: FEA Parameters and Loading Cases

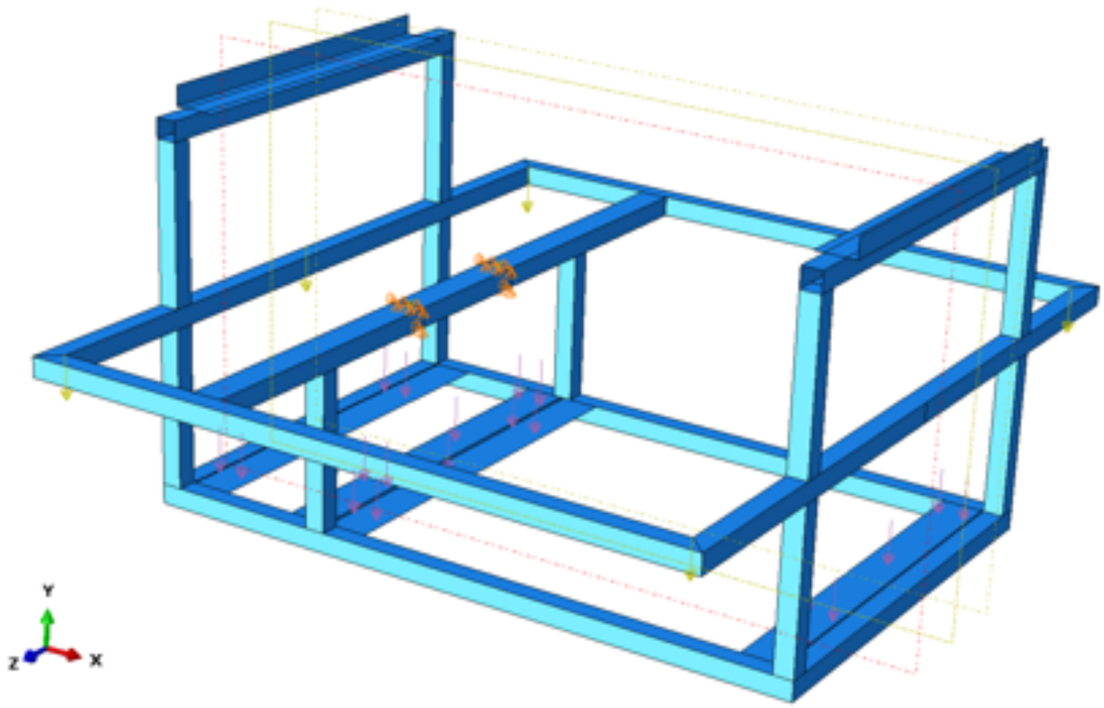


Figure O-1: Lifting Loading Case - Loads and Boundary Conditions

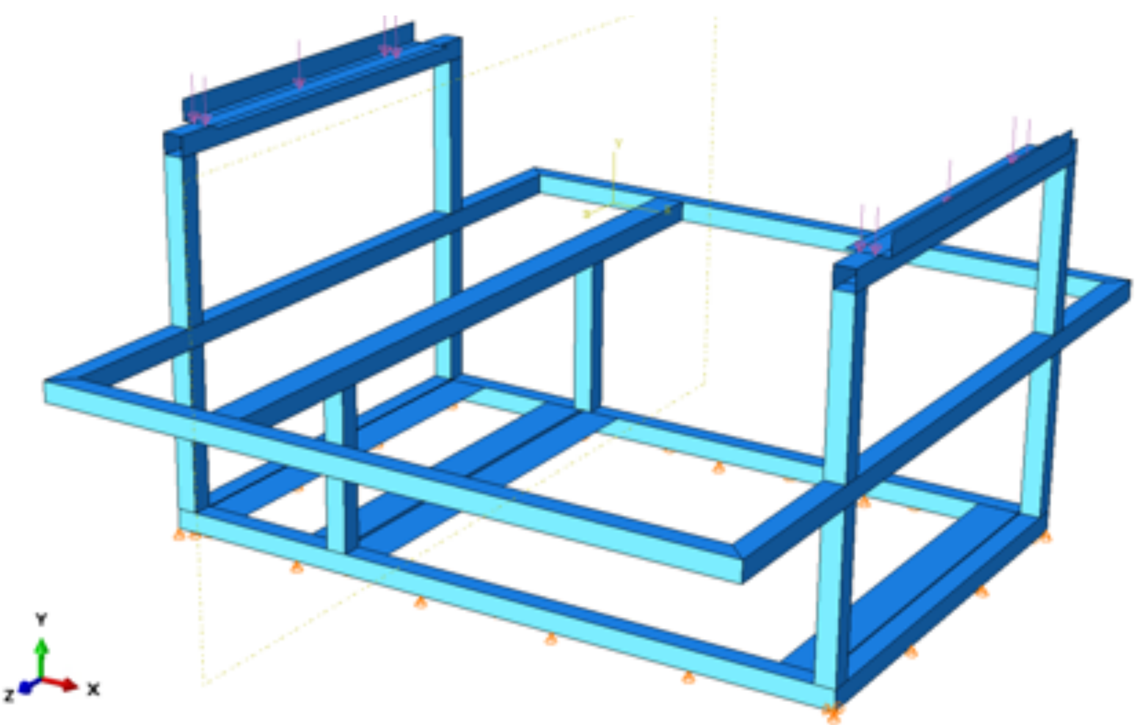


Figure O-2: Ground Stacking Loading Case - Loads and Boundary Conditions

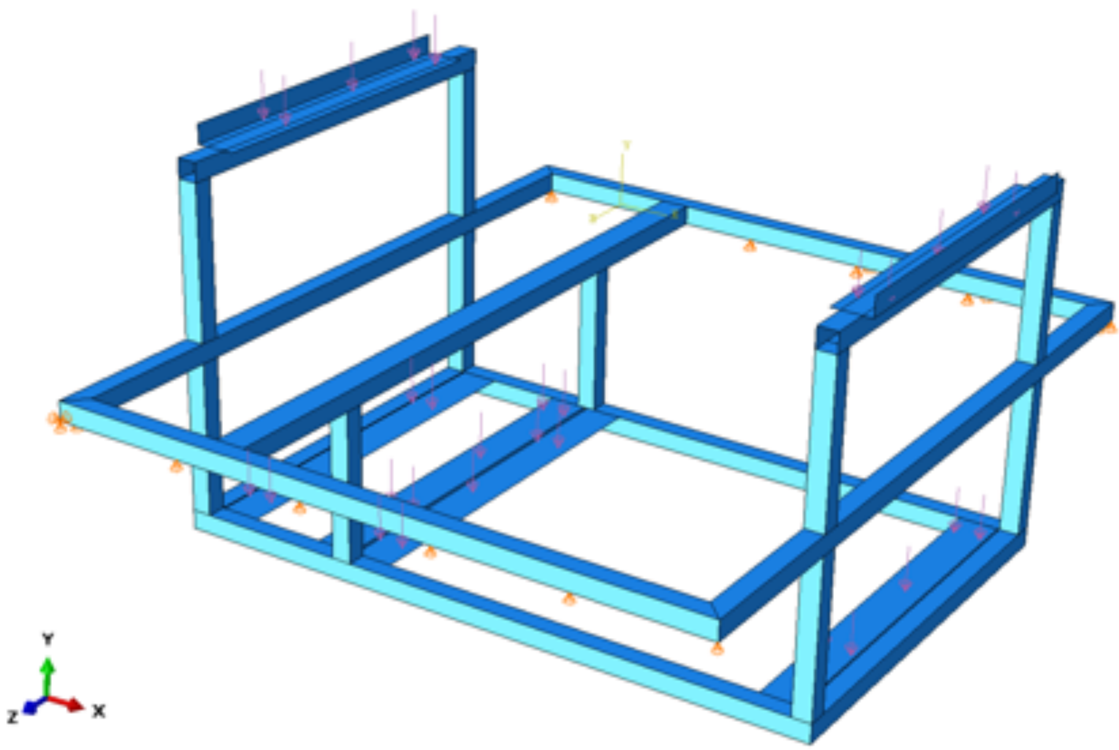


Figure O-3: Pontoon Stacking Loading Case - Loads and Boundary Conditions

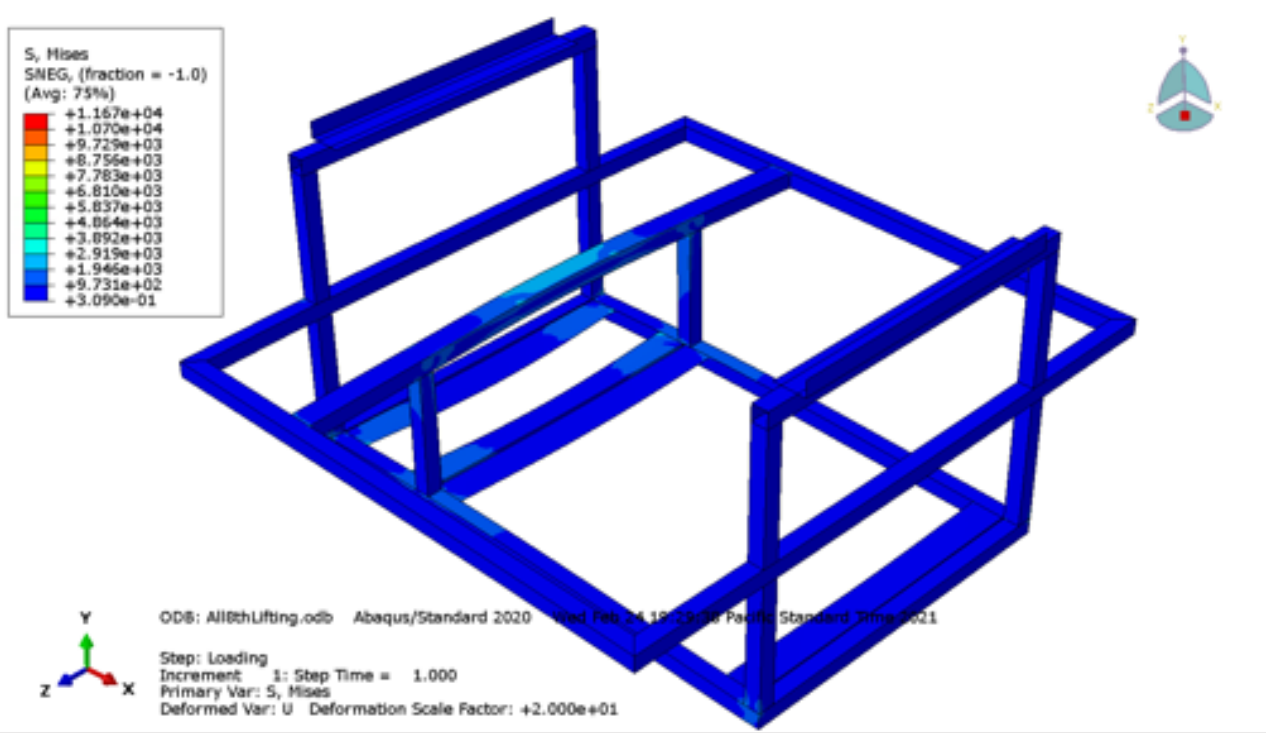


Figure O-4: Lifting Loading Case - Full Frame Mises Stress

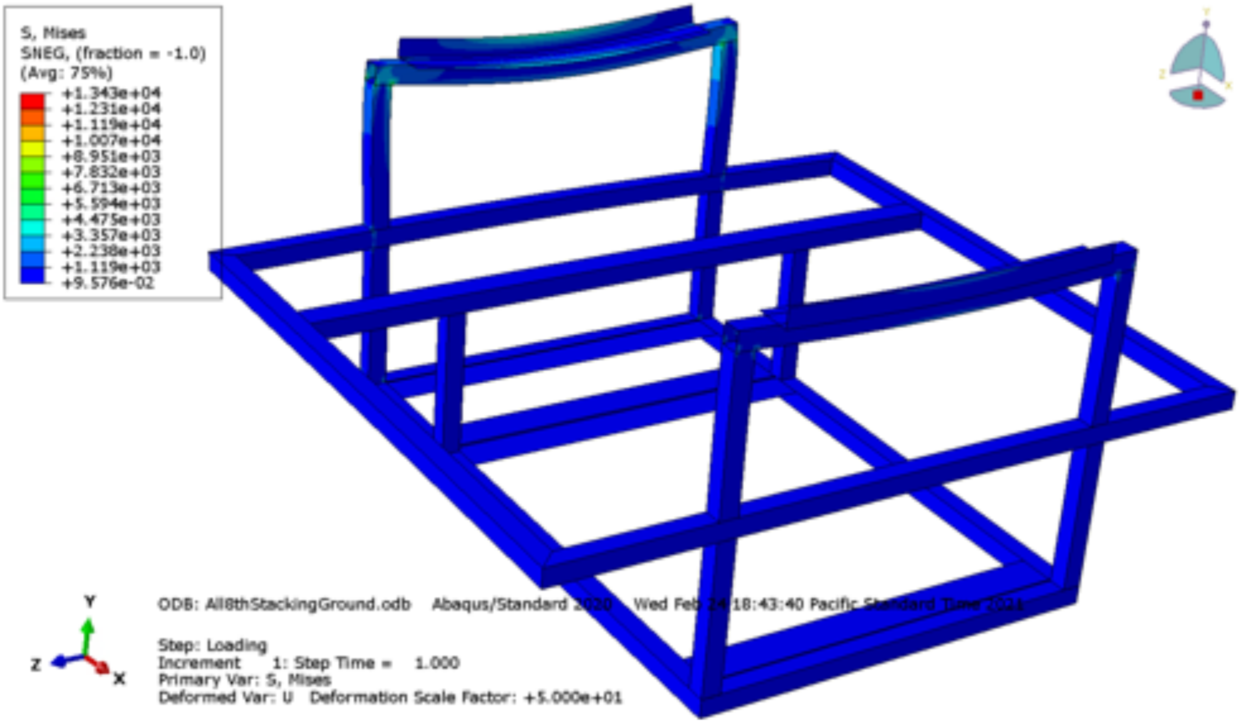


Figure O-5: Ground Stacking Loading Case - Full Frame Mises Stress

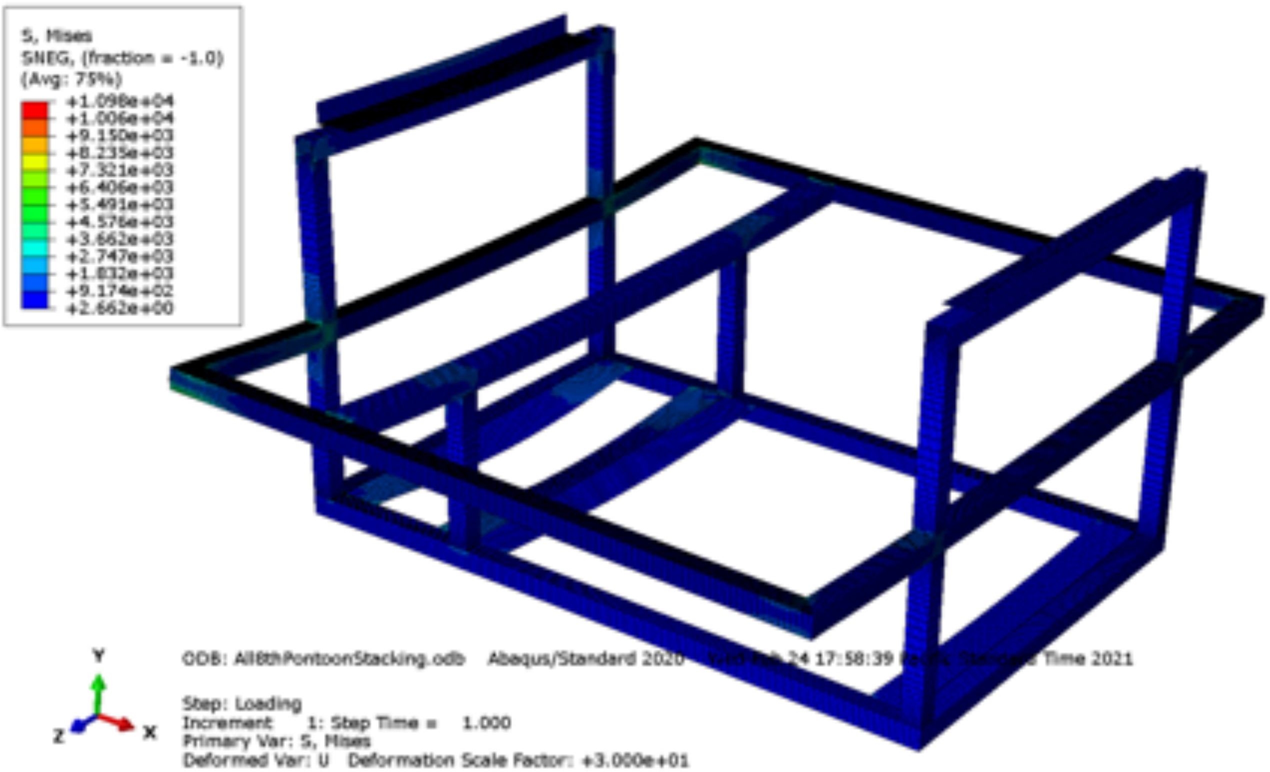


Figure O-6: Pontoon Stacking Loading Case - Full Frame Mises Stress

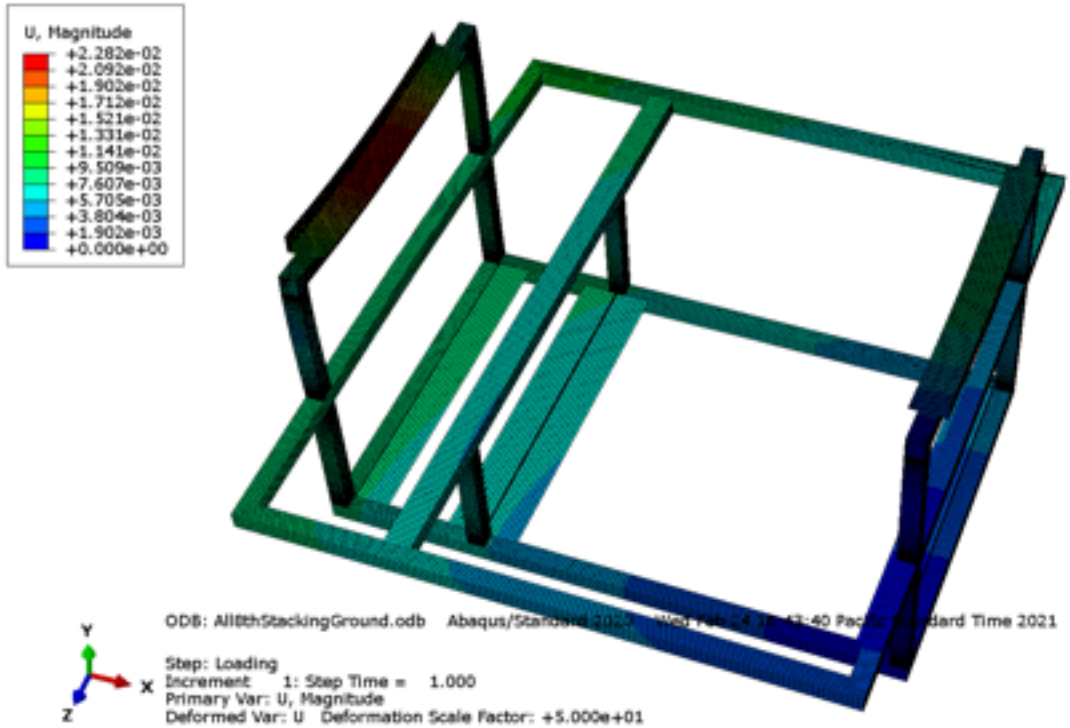


Figure O-7: Ground Stacking Loading Case – Deformation Plot

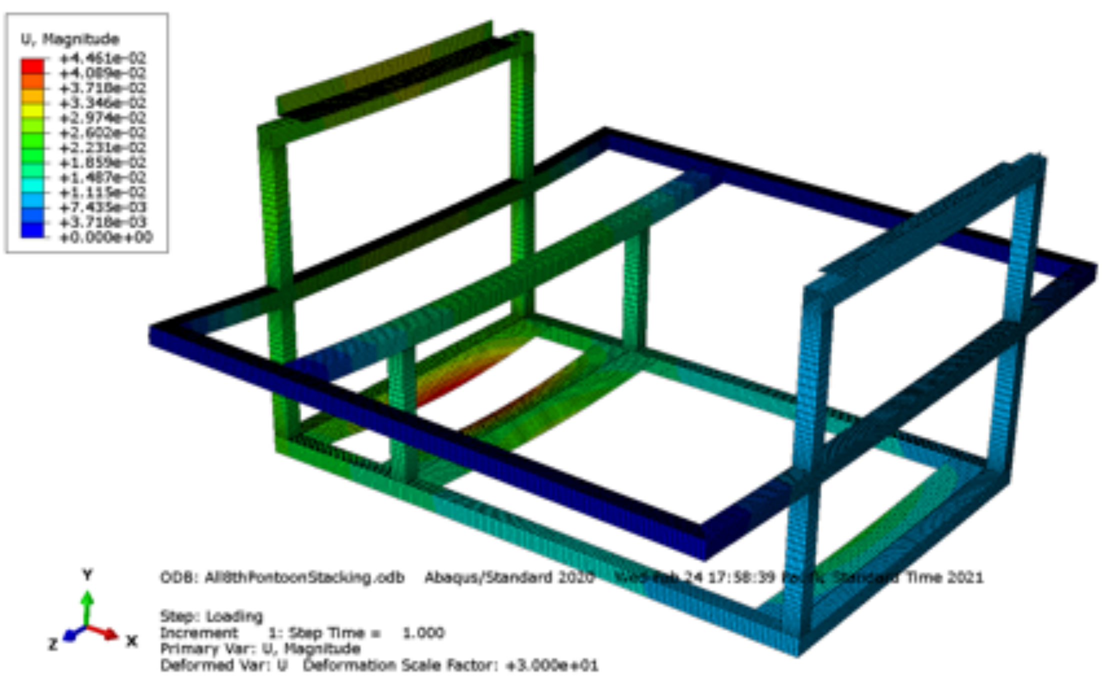


Figure O-8: Pontoon Stacking Loading Case – Deformation Plot

FEA Metal Properties:

AL 6061 – T6 Unwelded Areas	
Su	45000 [psi]
Sy	40000 [psi]

Groove Weld Strength – 6061 HAZ Properties w/ 5356 Filler	
Su	30000 [psi]
Sy	19000 [psi]

Fillet Weld Strength – 5356 Filler Properties	
S Long. Shear	26000 [psi]
S T. Shear	17000 [psi]

Loading Conditions:

Loading Case	Location	Max Mises Stress [psi]	SFY	SFU
Lifting	Main Lift Member Center	2083	19.2	21.6
Lifting	Main Lift Member - Support Fillet Welds	7281	2.6	4.1
Pontoon	Main Deck Width - Cross Joint (HAZ?)	2507	7.6	12
Pontoon	Main Deck Width - Cross Joint Fillet welds	5806	3.3	5.2
Pontoon	Main Deck Corners - Groove Weld	8309	2.3	3.6
Pontoon	Main Deck Corners - Fillet Weld	8600	2.2	3.5
Pontoon	Main Deck Lift Point Groove Weld	3541	5.4	8.5
Pontoon	Main lift Member Support Fillet Welds	4754	4	6.3
Ground	Upper Support Angle top edge	4075	9.8	9.8
Ground	Upper Support Tube Bottom Edge	3984	10	11.3
Ground	Upper Support Tube Fillet Weld	9500	2	3.2

P. Appendix P: Thruster Calculation Memo

MEMORANDUM

To:	Paul Nyholm,
	nyholm5@llnl.gov
CC:	Sam Fuller
	fuller41@llnl.gov
From:	Jacob Davis
	jdavis90@calpoly.edu
Date:	08 February 2021
RE:	**Research Raft Thruster Ordering**

Abstract:

To justify the selection of the motors that we intend to use as a group, I performed an analysis of the drag on the designed raft. In these drag calculations, I accounted for the pressure and skin friction drag on the pontoons under the water, the pressure drag on the portion of the raft above the waterline, and the drag due to created wake. Because of the complexity of the geometry above the water, I chose to neglect the skin friction drag on this portion of the raft. This simplification makes the analysis simpler. To calculate each of these drag components, I measured the relevant areas from the SolidWorks model, and consulted two different fluid dynamics textbooks for the relevant drag coefficient. By using these values in an Excel workbook, I calculated the drag force at the target speed of 5 ft/s as 12.14 lb_f. This is well within the limits of two of the intended motors; each of these motors are capable of outputting 8 lb_f when run at the voltage we have intended. Even with the simplifications made in this analysis, I am confident that these motors will meet the necessary specifications; further testing will confirm these results.

This memo includes the complete calculations for drag on the research raft, and the calculations for the hypothetical max speed of the craft with different numbers of motors.

Method:

The first step in the drag analysis is to complete a Free-Body Diagram (FBD) of the raft in steady state motion. Figure 1 shows this FBD.

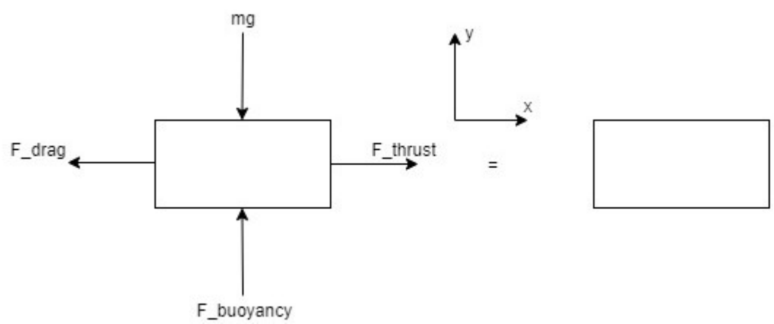


Figure 1. Free Body Diagram for research raft, assuming the raft is in steady motion and not accelerating.

From this FBD, the sum of the forces in the x-direction sum to the accelerations in the x-direction. Equation A.1 shows this equation.

$$\sum F_x = \sum ma_x \tag{A.1}$$

The FBD gives the forces in to substitute into this equation. Equation A.2 shows the forces deconstructed into their separate components.

$$F_{thrust} - F_{drag,pressure} - F_{drag,friction} - F_{drag,wave} - F_{drag,air} = 0 \tag{A.2}$$

Each of these components is drag from a different portion of the raft. $F_{drag,pressure}$ is the drag due to the pressure on the front of the pontoons under the water, while $F_{drag,friction}$ is the drag due to skin friction over the pontoons underwater. $F_{drag,wave}$ is the drag force to represent the energy dissipated while making waves as the raft moves over the surface of the water. $F_{drag,air}$ is the pressure drag on the front of the raft, considering both the payload and the pontoons above the water. I chose to neglect the skin friction over this portion of the raft for a couple reasons. The first is that the geometry is complex, and the formulas in the fluids textbooks that I referenced do not have analytical or empirical formulas to best quantify the drag coefficient. The second reason is that the surfaces in this portion of the raft vary in texture; therefore, the skin friction coefficients differ wildly, making the calculation difficult. We could complete a more precise analysis with the use of computational fluid dynamics, but we do not have the skills to appropriately model and analyze results from this type of analysis.

Each of the terms in Equation A.2 can rewritten by rearranging the definition of the drag coefficient. Equation A.3 shows the rearranged formula for the drag coefficient.

$$F_{drag} = C_D \frac{1}{2} \rho V^2 A \tag{A.3}$$

Substituting Equation A.3b into Equation A.2 gives the complete equation for the thrust needed to overcome the drag on the research raft. This complete expression is in Equation A.4.

$$\begin{aligned} F_{thrust} = {} & C_{D,pressure} \frac{1}{2} \rho_{water} V^2 A_{pontoon,frontal} \\ & + C_{D,friction} \frac{1}{2} \rho_{water} V^2 A_{pontoon,surface} \\ & + C_{D,wave} \frac{1}{2} \rho_{water} V^2 L^2 + C_{D,air} \frac{1}{2} \rho_{air} V^2 A_{raft,frontal} \end{aligned} \tag{A.4}$$

Each of the areas in Equation A.4 is a different area, depending on the drag. The pressure drags are based on a frontal areas, the skin friction drag is based on the surface area over which the fluid flows, and the wave drag is based on the length of the craft at the surface of the water. These dimensions were taken from the CAD model, using section views and the measure tool. Additionally, each drag coefficient is from a reference text, for that specific drag case. Table 1 shows all these areas, drag coefficients, and source if applicable.

With these values, I moved the calculations into Excel, to allow for easier iteration.

Table 1. Coefficients and constants to calculate the thrust needed to propel the raft through the water.

Constant	Variable	Value	Units	Source
Pressure Drag Coefficient, below water	$C_{D,P}$	0.38	--	[1]
Friction Drag Coefficient, below water	$C_{D,F}$	0.0037	--	[2]
Wave Drag Coefficient	$C_{D,W}$	0.00225	--	[3]
Pressure Drag Coefficient, above water	$C_{D,A}$	1.05	--	[1]
Pontoon Frontal Area	$A_{F, Pontoon}$	0.322	ft^2	
Pontoon Surface Area	$A_{S, Pontoon}$	8.87	ft^2	
Raft Frontal Area	$A_{F, Raft}$	3.55	ft^2	
Pontoon Length, at water's surface	L	6.44	ft	
Water Density	ρ_{water}	62.35	lbm/ft^3	[5]
Air Density	ρ_{air}	0.076	lbm/ft^3	[6]

Results:

The results from the Excel spreadsheet indicate that the drag on the raft will be 12.14 lb_f at a speed of five feet per second. Most of this drag is due to the pressure on the front of the pontoons and due to the waves created by the raft as it moves. This result is based on a few assumptions, which may influence the results. The first of these assumptions is regarding the drag on the front of the pontoons. The complex geometry of this surface is not standard; to approximate the drag on this surface, I used the drag coefficient for a hemisphere with the flat surface downstream. While not a perfect approximation, this coefficient should over approximate the drag on these surfaces.

The second assumption that I made is that the pontoon surface under the water is approximated as a flat plate. This simplifies the skin friction drag on the surface. Instead of needing to perform an integral of the shear stress over the surface of the pontoon, I used the equation for drag as a function of the Reynolds number. This simplifies the analysis necessary for this problem and should not alter the results much.

Using Excel to perform the calculations allowed me to take advantage of the solver tool. I used this tool to find the maximum velocity for a given drag. The current raft design allows us to mount two or four motors on the frame, depending on the current needs. For two motors, with a total of 16 lb_f, the maximum velocity is 5.75 feet per second. For four motors, with a total of 32 lb_f, the maximum velocity is 8.16 feet per second. Both values exceed the specified tolerances that we have set for the project.

These calculations do not consider the difference in air and water speeds. When I take air speed into consideration, the drag force becomes 19.89 lb_f for a 25 knot wind and 5 feet per second travel speed. This may be too much for our chosen motors to handle, but we will confirm the actual speeds with testing. Even if two motors cannot accommodate this drag, four motors definitely will, and given the space on the raft, we are confident that our thruster choice will move the raft in the desired manner.

In addition to these calculations, we will be running tests to verify the maximum velocity of the raft when assembled. While these calculations serve as the basis for ordering, the simplifying assumptions made require an empirical validation. I am confident that the empirical data will support these calculations.

References:

[1] Pritchard, Philip and John Mitchell. *Fox and McDonald's Introduction to Fluid Mechanics*. 9th ed., Wiley & Sons, 2015, pg 379.

[2] Pritchard, Philip and John Mitchell. *Fox and McDonald's Introduction to Fluid Mechanics*. 9th ed., Wiley & Sons, 2015, pg 376.

[3] Munson, Bruce et al. *Fundamentals of Fluid Mechanics*. 7th ed., Wiley & Sons, 2013, pg 526.

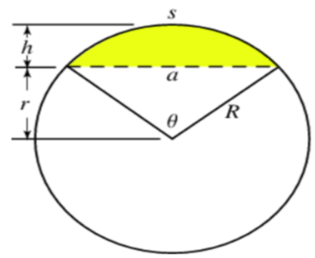
[4] Engineering Toolbox. "Water - Dynamic and Kinematic Viscosity." Engineering ToolBox, 2004, www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html.

[5] Engineering Toolbox. "Air - Dynamic and Kinematic Viscosity." Engineering ToolBox, 2003, www.engineeringtoolbox.com/air-absolute-kinematic-viscosity-d_601.html.

Q. Appendix Q: Thruster Calculation Excel Workbook

PRIMARY VESSEL SPECS.

Wf	200	lbf	Raft weight (frame, pontoons, motors, etc)
Wb	68	lbf	battery weight
Wp	10	lbf	payload weight (removable payloads from box)
Wtotal	278	lbf	Total weight (= total boyant force)
rho	62.4	lbf/ft^3	Density of water
Vsub	4.46	ft^3	Total Submerged volume
Vsub1	2.23	ft^3	submerged volume of one pontoon



$$= R^2 \cos^{-1}\left(\frac{R-h}{R}\right) - (R-h)\sqrt{2Rh - h^2},$$

F_thrust = F_drag
= F_pressure + F_friction + F_wave + F_air
= 2*Cd_pressure*0.5*rho*V^2*A_front
+ 2*Cd_friction*0.5*rho*V^2*A_surface
+ Cd_wave*0.5*rho*V^2*L^2
+ Cd_air*0.5*rho*V^2*A_front,air

Assumes a cylindrical pontoon with flat ends

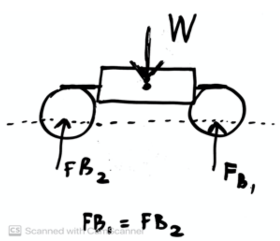
PONTOON SPECS

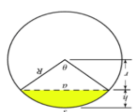
L (ft)	OD (in)	R (in)	V (ft^3)	Asub (ft^2)	Asub (in^2)
6	18	9	10.60	0.371	53.462

Volume of Maravia Pontoons (obtained from CAD) each	
in^3	ft^3
15826	9.16

Assumptions

Zero Acceleration of the raft
Pontoons can be approximated as cylinders
Water is incompressible
Turbulent Flow





SumFy = -W + FB1 + FB2 = 0
W = FB1+FB2
W = FBtotal

Constants

Specification	Variable	Value	Units	Value	Units
Ocean Temp		62.6F			
Air temp at Surface		60.9F			
Frontal Area, water	A_front	46.37	in^2	0.32	ft^2
Surface Area, water	A_surface	1277.51	in^2	8.87	ft^2
Frontal Area, raft	A_raft	511.86	in^2	3.55	ft^2
Density, water	rho	62.35	lb/ft^3		
Density, air	rho	0.07617	lb/ft^3		
Cylinder Length	L	77.24	in	6.44	ft
Raft Length	L	96.46	in	8.04	ft
Gravity	g	32.2	ft/s^2		

Givens:

Specification	Variable	Value	Units
Velocity, water	V	8.16	ft/s
Viscosity, water	mu	0.000022537	lbf*s/ft^2
Velocity, air	V	8.159380603	ft/s
Viscosity, air	mu	3.746E-07	lbf*s/ft^2

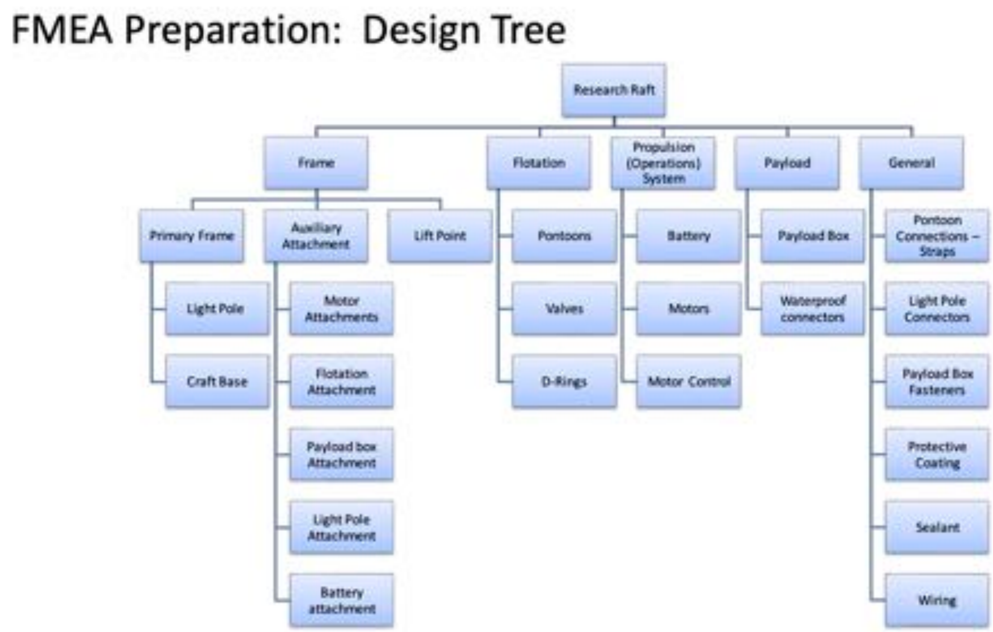
Specification	Variable	Value
Reynolds, water	Re	4512349.11
Reynolds, air	Re	414174.65
Froude	Fr	0.57

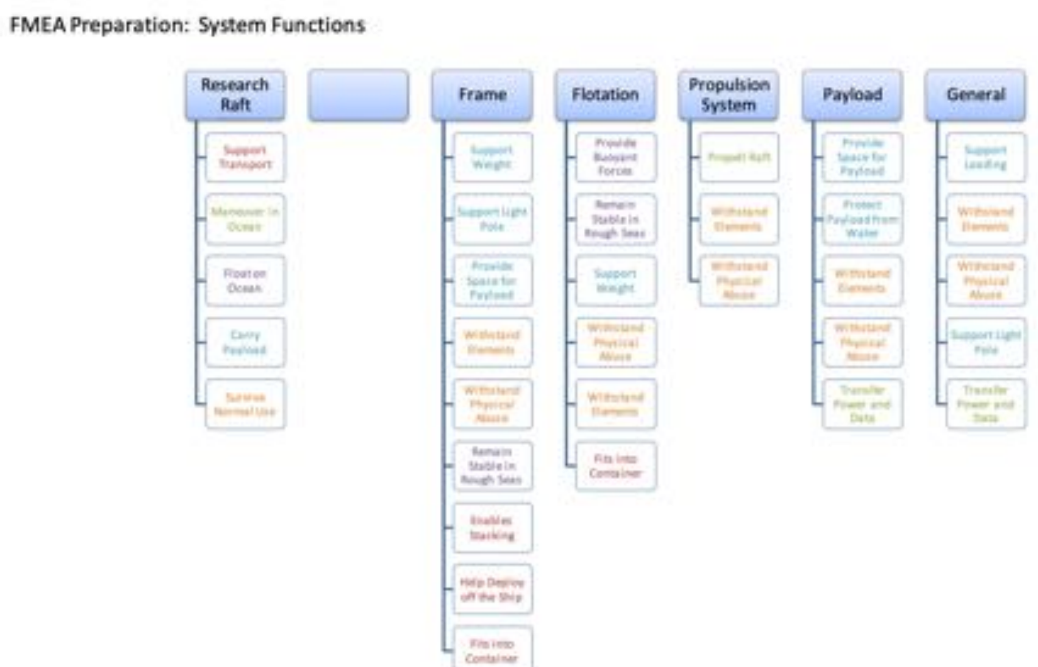
Specification	Variable	Value
Cd_friction	Cd_f	0.0034
Cd_pressure	Cd_p	0.38
Cd_wave	Cd_w	0.00225
Cd_air	Cd_a	1.05

Specification	Variable	Value	Units
F_friction	F_f	3.91	lbf
F_pressure	F_p	15.77	lbf
F_wave	F_w	12.02	lbf
F_air	F_a	0.29	lbf

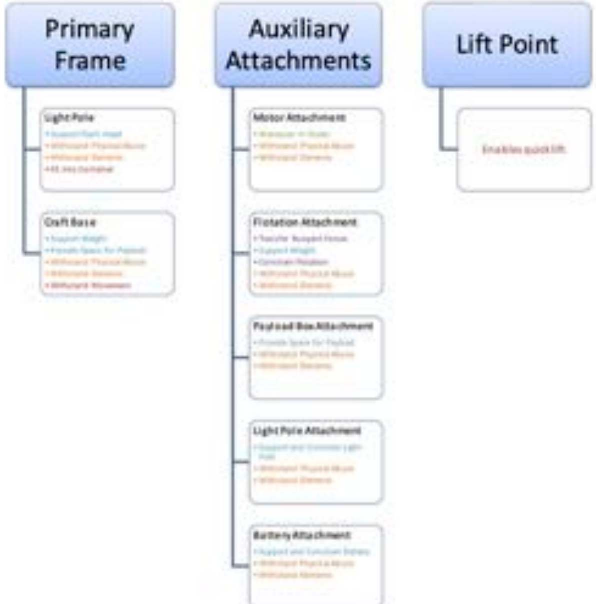
Specification	Variable	Values	Units
F_drag	F_d	32.00	lbf
F_thrust	F_t	32.00	lbf

R. Appendix R: FMEA Design Trees

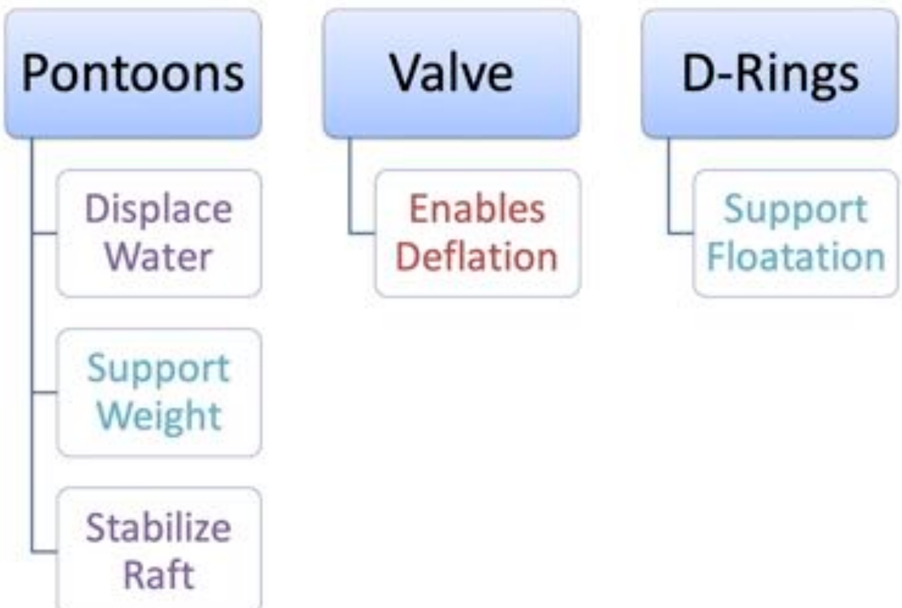




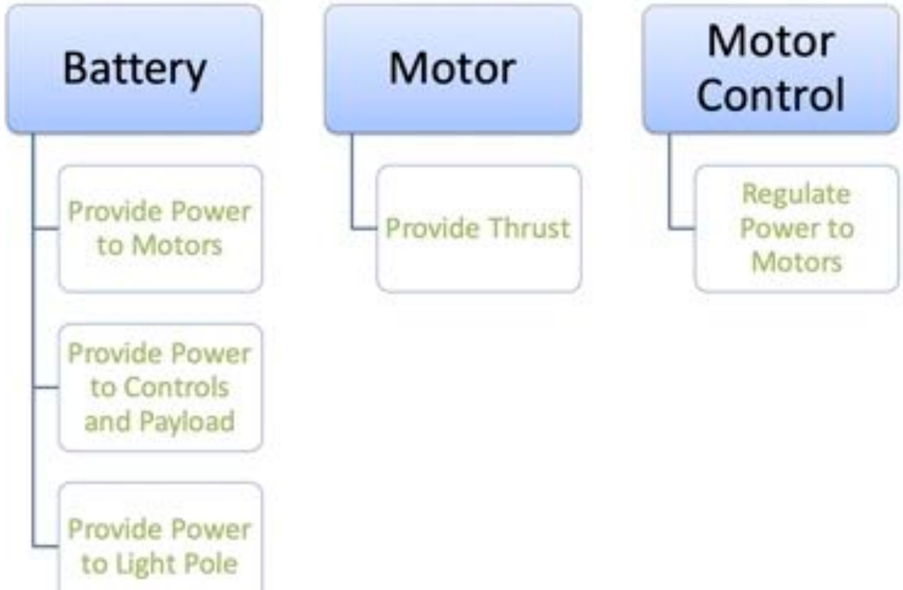
FMEA Preparation: Component Functions - Frame



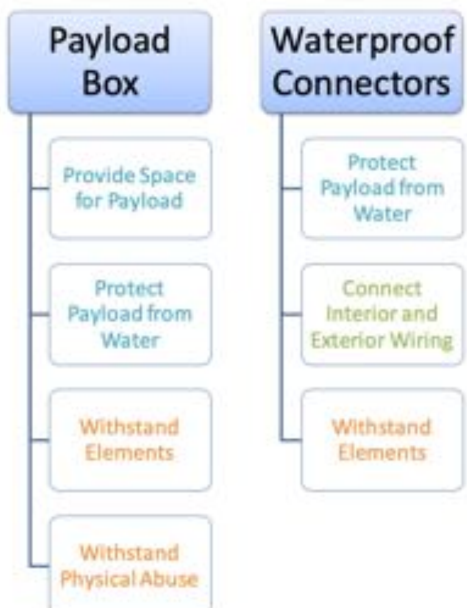
FMEA Preparation: Component Functions - Floatation



FMEA Preparation: Component Functions – Propulsion System

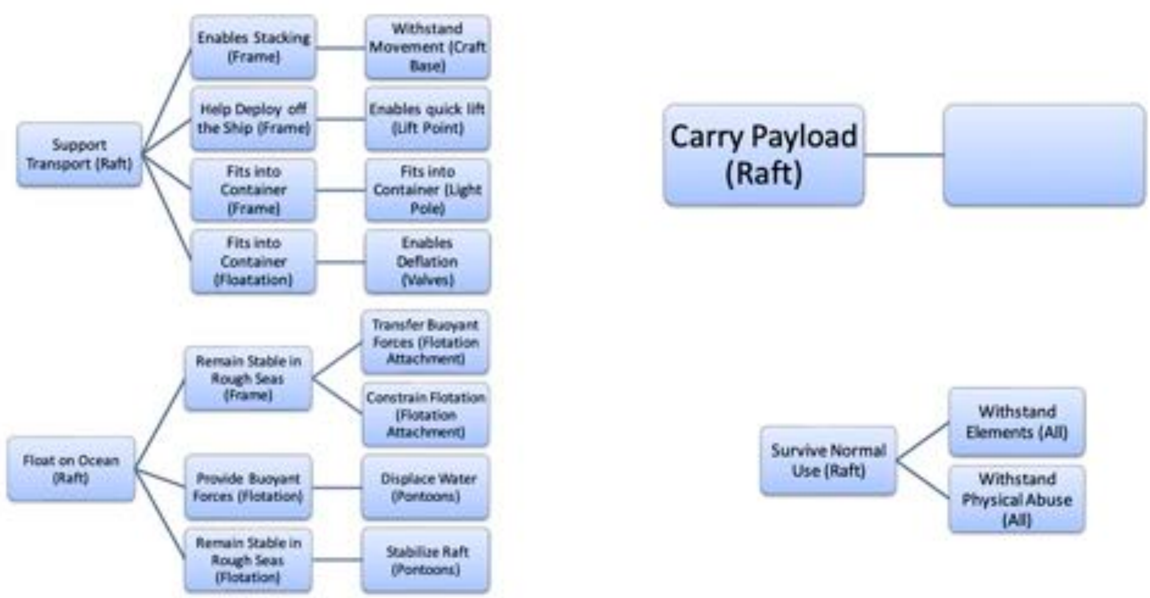


FMEA Preparation: Component Functions - Payload



FMEA Preparation: Component Functions - General

FMEA Preparation: Function Trees



FMEA Preparation: Function Trees

S. Appendix S: FMEA Table

Full system analysis presented with secondary table on high-risk systems highlighted in orange.

System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurrence	Current Detection Activities	Detection	Priority
FRAME	--	--	--	--	--	--	--	--	--
Frame / Support Weight	Frame breaks	Raft sinks	8	1) Base is too weak 2) Base cracks	Structural Analysis, Design	4	Frame physical testing	1	32
	Frame bends	Raft operation is impaired Raft must be repaired	7	1) Base deforms excessively 2) Base is too weak	Structural Analysis, Design	5	Frame physical testing	1	35
Frame / Support Light Pole	Light pole detaches	Raft must be repaired	5	1) Pole cannot support loading 2) Pole attachment stresses pole to breakage 3) Pole attachment fractures under loading 4) Pole attachment is not properly sized for the pole	Structural Analysis, Design	2	Pole attachment physical testing	1	10
	Light pole deflects excessively	Raft must be repaired	5	1) Pole is not stiff enough	Structural Analysis, Design	3	Pole physical testing	1	15
Frame / Provide Space for Payload	Box becomes unsecured	Payload is damaged	6	1) Base is too weak to support box 2) Not enough attachment points are used 3) Supports are too large	Structural Analysis, Design	4	Frame physical testing	1	24
	Frame doesn't accommodate the box	No space for payload on raft	8	1) Base is too small 2) Supports are too small 3) Supports do not provide space for clearance	Inspection during design. CAD Models	1	Prototype Frame inspection, Payload Implementation testing	1	8
Frame / Withstand elements	Frame oxidizes	Raft corrodes	2	1) Base is made of metal 2) Light pole is made of metal 3) Flotation attachment is made of metal 4) Motor attachment is made of metal 5) Payload box attachment is made of metal 6) Battery attachment is made of metal 7) Lift point is made of metal 8) Any part of the frame or attachments warp under conditions	Proper Material Selection, Protective coating	7	Research, Visual inspection	5	70
Frame / Withstand Physical Abuse	Connections break	Raft Sinks Raft must be repaired	8	1) Connections to any attachment is too weak (Motor, Payload, Battery, Light pole, Flotation)	Structural Analysis, Design	5	Frame physical testing	1	40

	Frame breaks	Raft Sinks Raft must be repaired	8	1) Any part of the frame and attachments breaks under loading 2) Any part of the frame and attachments break under impact 3) Any part of the frame and attachments breaks under transport 4) Any part of the frame and attachments warp under loading	Structural Analysis, Design	4	Frame physical testing	1	32
	Deformation	Raft operation is impaired Raft must be repaired	7	1) Any part of the frame and attachments deforms under loading	Structural Analysis, Design	5	Frame physical testing	1	35
Frame / Remain Stable in rough seas	Frame is not wide enough to keep the raft stable	Raft flips	7	1) Base is too small 2) Flotation attachment is over or undersized	Stability Calculations, Stability Testing	2	Stability testing	4	56
Frame / Enable Stacking	Frame cannot support weight of another frame	Raft cannot be stacked	5	1) Base is too weak 2) Flotation attachment is bends or breaks	Structural Analysis, Design	2	Frame physical testing	1	10
	Frame damages pontoons	Raft cannot be stacked Raft must be repaired	5	1) Motor attachments interfere with pontoons 2) Any frame component is sharp and damages the raft 3) Flotation attachments are not sized properly	Inspection during design. CAD Models	6	Frame prototype inspection	4	120
	Frame causes interference	Raft cannot be stacked	5	1) Flotation attachment causes interference between rafts 2) Motor attachment causes interference between rafts 3) Light Pole cannot detach from the raft 4) Lift point causes interference between rafts	Inspection during design. CAD Models	2	Prototype measurement. Scale model stacking tests	2	20
Frame / Help Deploy off the ship	Frame breaks under own weight	Raft doesn't deploy	9	1) Lift point is too small 2) Lift point is too weak	Structural Analysis, Design	3	Frame physical testing	1	27
	Frame is too heavy	Raft relies on heavy equipment Raft is too heavy to ship	6	1) Frame and attachments are too heavy 2) Lift point cannot support the weight of the frame	Frame design, Material Selection	2	Cad weight predictions, prototype weight measurements	1	12
	Frame cannot be lifted	Raft doesn't deploy	8	1) Lift point is not easily accessible 2) Lift point is too small 3) Lift point is too weak 4) Lift point is slippery when wet	Lift point design	1	Lift point physical testing	1	8
Frame / Fits into container	Frame is too large	Raft is too large to ship	6	1) Light pole cannot detach 2) Base is too big 3) Motor attachments are too big	Inspection during design. CAD Models	1	Frame inspection, shipping dimensions test	1	6
FLOTATION	--	--	--	--	--	--	--	--	--
Flotation / Provide Buoyant Forces	Flotation deflates	Raft sinks Raft Submerges	8	1) Pontoons leak air 2) Pontoons tear 3) Valves are not tight	Flotation Sizing / Selection	5	Floatation buoyancy test, Physical testing	2	80

	Flotation detaches	Raft sinks	8	1) Straps to fail secure flotation	Flotation Connection design / selection	3	Strap physical testing	2	48
Flotation / Remain Stable in Rough Seas	Flotation deflates	Raft flips	7	1) Pontoons leak air 2) Pontoons tear 3) Valves are not tight	Flotation Sizing / Selection	5	Valve testing / inspection	2	70
	Flotation translates with respect to the raft	Raft does not maneuver properly in ocean	5	1) Straps fail to secure flotation	Flotation Connection design / selection	2	Strap physical testing	3	30
Flotation / Support Weight	Flotation deflates	Raft sinks Raft submerges	8	1) Pontoons leak air 2) Pontoons tear 3) Valves are not tight	Flotation Sizing / Selection	5	Floatation physical testing	3	120
Flotation / Withstand Physical Abuse	Flotation tears	Raft sinks Raft submerges Raft must be repaired	8	1) Floatation wears 2) Exposed to sharp edges	Flotation Sizing / Selection	5	Floatation physical testing	6	240
	Flotation disconnects from frame	Raft sinks Raft must be repaired	7	1) Flotation not secured 2) Straps fail	Flotation Connection design / selection	3	Strap physical testing	3	63
	Flotation leaks air	Raft submerges Raft must be repaired	7	1) Pontoons leak air 2) Pontoons tear 3) Valves are not tight	Flotation Sizing / Selection	5	Valve testing / inspection	3	105
Flotation / Withstand Elements	Flotation wears out	Raft wears out too quickly	3	1) Pontoons are weak 2) Low life on components	Flotation Sizing / Selection	5	Research	7	105
	Flotation leaks air	Raft must be repaired	6	1) Pontoons leak air 2) Pontoons tear 3) Valves are not tight	Flotation Sizing / Selection	5	Valve testing / inspection	7	210
Flotation / Fits into container	Flotation doesn't deflate	Raft is too large to ship	5	1) Seal too tight	Flotation Sizing / Selection	2	Floatation inflation / deflation test	1	10
	Flotation is too large	Raft is too large to ship	5	1) Overdesigned to support weight	Flotation Sizing / Selection	2	Floatation inspection	1	10
PROPULSION SYSTEM	--	--	--	--	--	--	--	--	--
Propulsion / Propel Raft	Prop system doesn't work	Raft won't maneuver in ocean	7	1) Battery fails 2) Battery life drained 3) Battery loses connection to motor 4) Motors are damaged 5) Motors gets disconnected	Battery Sizing Calculations, Motor protection design	4	Battery capacity test, connection check, visual inspection	5	140
	Prop system doesn't meet speed requirement	User will be unsatisfied	5	1) Battery doesn't produce enough power 2) Low battery life 3) Motor thrust too weak 4) Motor configuration doesn’t provide efficient thrust	Battery Sizing Calculations, , Motor selection / thrust calculations	2	Prototype testing	1	10

	Prop system doesn't allow raft to rotate	Raft does not maneuver properly in ocean	6	1) Battery life low 2) Motor does not provide enough thrust 3) Motors fail 4) Motor configuration is inefficient	Battery Sizing Calculations, , Motor selection / thrust calculations, Efficiency Calculations	4	Prototype testing	2	48
Propulsion / Withstand Elements	Prop system corrodes	1) Props won't operate properly 2) Prop system will have to be replaced	5	1) Motors control gets wet 2) Prop system isn't properly maintained	Motor control enclosure design	7	Visual inspection	5	175
	Prop system isn't waterproof	1) Props system will sustain damage 2) Prop system must be replaced	6	1) Motors control gets wet 2) Prop system isn't properly maintained	Motor Selection, Motor maintenance Schedule, sealed components	3	Testing, Visual inspection	2	36
	Prop system overheats	Prop system will stop functioning	6	1) Battery produces too much power 2) Battery specs not compatible 3) Motors provide too much thrust 4) Motor control cannot handle load	Motor Selection, Motor maintenance schedule, motor monitoring	3	None	2	36
Propulsion / Withstand Physical Abuse	Prop system components disconnect	Prop system will not work	8	1) Battery gets damaged 2) Motor gets damage/breaks 3) Motor control gets damaged	Redundant connections, connection selection	3	Visual inspection, connection check	5	120
	Prop system gets damaged	Prop system will not work properly	7	1) Battery gets damaged 2) Motor gets damage/breaks 3) Motor control gets damaged	Frame design for protection, designed connections and supports	5	Physical testing	5	175
PAYLOAD	--	--	--	--	--	--	--	--	--
Payload / Provide Space for Payload	System isn't large enough	No space for payload on raft	7	1) Payload box does not have enough volume for payload 2) Payload box min. dimensions too small for payload	Payload box selection	1	Design for adequate space	1	7
	Payload cannot be properly oriented	Payload does not operate properly	7	1) Payload box min. dimensions too small for payload 2) Payload box location impairs payload function	Payload box selection, payload space design	2	Design for proper orientation	1	14
Payload / Protect payload from water	Payload system lets in water	Payload is damaged	6	1) Payload box is not sealed 2) Water can collect in payload box 3) Connectors are not sealed	Payload box seal selection, payload box seal testing	3	Run waterproof test	2	36

Payload / Withstand Elements	Payload system corrodes	Payload system must be replaced	3	1) Payload box corrodes 2) Connectors corrode	1) Use corrosion resistance components for payload system 2) Clean and run maintenance on payload system	2	Inspect payload system	3	18
	Payload system is impaired by salt	Payload system must be repaired / replaced	3	1) Connectors damaged by salt 2) Payload box hinges / latches impaired by salt	Clean and maintain payload system	2	Inspect payload system	3	18
Payload / Withstand Physical Abuse	Payload system is damaged	Payload system must be replaced Payload does not operate properly	6	1) Payload system is dented / deformed 2) Payload box breaks	1) Use robust and durable payload box	2	Visually inspect payload system	4	48
	Payload is damaged	Payload does not operate properly	7	1) Payload system is dented / deformed 2) Payload box breaks	Ensure payload is properly protected	2	Inspect payload system	4	56
Payload / Transfer Power and Data	Data cannot be transferred	Payload does not operate properly	5	1) Connectors do not transmit data	1) Consult reliability of electrical schematics	4	Test data transfer system	4	80
	Payload cannot be powered	Payload does not operate properly	5	1) Connectors do not transmit power	1) Consult reliability of electrical wiring	3	Payload system inspection	4	60
GENERAL	--	--	--	--	--	--	--	--	--
General / Support Loading	System connections fail	Payload does not operate	6	1) System connectors fail under loading 2) Connectors inhibit system function 3) connectors are not easily accessible	1) Design connections with higher safety factor	6	FEA	7	252
	Components become disconnected	Payload does not operate	5	1) Connectors become detached 2) Connectors deform	1) Design connections with higher safety factor	4	FEA	2	40
General / Withstand Elements	Ocean environment causes mechanical failure	1) Mechanical components must be repaired/replaced 2) Raft will not function	7	1) Sealant does not protect components 2) Protective coating does not protect component 3) Protective coating is worn off	1) Use proper sealant for saltwater conditions 2) Use coating with increased durability 3) Use layers of coating or sealant in high-risk areas	6	Research / visual inspection	6	252
	Ocean environment causes electrical failure	1) Electrical components will not function 2) Components must be repaired	7	1) Water causes electrical system to short 2) Environmental elements build up leading to connections not working	1) Use waterproof connectors 2) Clean components after each use	4	visual inspection	3	84

	Ocean elements cause buildup on raft components	1) Raft corrodes 2) Raft is ugly 3) Raft wears out 4) Raft must be repaired	2	1) Components are not designed to withstand ocean environment 2) The sealant does not protect components 3) Protective coating chips or fails	1) Use marine focused products 2) Clean components after each use	2	visual inspection	3	12
General / Withstand physical abuse	System connections fail on impact	1) Components must be replaced 2) System fails	4	1) Components are not designed to accurate stress conditions	1) Preform stress analysis on estimated loading conditions	6	1) component specifications vs intended loading 2) Checking connection	5	120
	Systems connections disconnect easily	1) Raft will not function properly	6	1) Connecting elements cannot support physical loading and stress experienced in use	1) Avoid stress on connection elements through correct sizing 2) Design connections with higher safety factor	2	1) component specifications vs intended loading 2) Checking connection	3	36
General / Support Light Pole	Light pole does not stay upright	1) Light will not be seen	4	1) Connector does not secure light pole 2) Connector cannot support loading	1) Design connections with higher safety factor	1	FEA	2	8
	Light pole experiences damaging deflection	1) Light pole will not work properly	5	1) Connector does not secure light pole	1) Design connector with appropriate clearance	1	Research on flash pole dynamics	2	10
General / Transfer Power and Data	Electrical system loses power	1) Raft will not propel 2) payload will not function 3) User cannot control raft	7	1) Wiring cannot support loading 2) Wiring becomes fractured or kinked 3) Wiring is too complex to assemble correctly	1) Use wiring harness 2) Size wire accordingly 3) Ensure clearance for wire with length and space	3	1) Electrical loading calculations 2) Visual inspection on wiring system	1	21
	Electrical system cannot support load	1) Motors will not propel raft properly	7	1) Wiring cannot support electrical loading 2) Wiring cannot support physical loading	1) Size wire accordingly	1	Electrical loading calculations	1	7

Critical System Functions:

System / Function	Potential Failure Mode	Priority	Recommended Action	Responsibility and Target Completion Date	Actions Taken	Updated Severity	Updated Occurrence	Updated Detection
Flotation / Withstand Physical Abuse	Flotation Tears	240	1) Ensure maintenance, treatment, and repair plans are in place 2) Communicate with sponsor to ensure current process will detect or minimize a failure	Kahye 06/04/21	User manual provided outlining proper procedures and maintenance.			
Flotation / Withstand Elements	Flotation Leaks Air	210	1) Ensure use guidelines match current processes to reduce occurrence of failure and increase detection of leaks should they occur. Recommend aggressive use testing	Kahye 06/04/21	User manual provided outlining proper procedures and maintenance.			
Propulsion / Withstand Elements	Prop System Corrodes	175	1) Ensure maintenance, treatment, and repair plans are in place 2) Communicate with sponsor to ensure current process will detect or minimize a failure	Andrew 06/04/21	User manual provided outlining proper procedures and maintenance.			
Propulsion / Withstand Physical Abuse	Prop System Components Disconnect	120	Research durable and robust connections then will minimize possible disconnections	Kahye 02/12/21	Determined the best option would be to wire the motors to the electronics with an easily replaceable, robust, external connector, to make the problem easy to detect and less likely to occur.	8	1	2
Propulsion / Withstand Physical Abuse	Prop System is Damaged	175	Research into ocean conditions and evaluate physical design to minimize damage in the ocean.	Luke 02/12/21	Researched material choice options for the frame and the payload box. Recommended materials that should protect the electronics, battery, and motor from damage.	7	2	5
General / Support Loading	System Connections Fail	252	Research into use conditions and running aggressive FEA to model the most extreme case.	Andrew 02/12/21	Ran FEA simulations to ensure the welded connections would be strong under a variety of loading conditions.	6	2	7
General / Withstand Elements	Ocean Environment Causes Mechanical Failure	252	Research the long-term effects of environmental effects of use in an ocean setting. Materials can be selected to best combat challenges but ultimately it will depend on maintenance.	Luke 02/12/21	Ordered a pontoon with a protective coating that will last in an alkaline environment for an extended timeframe. The aluminum frame should resist corrosion.	7	2	2

T. Appendix T: Manufacturing Plan

Manufacturing Plan

Lawrence Livermore National Labs Research Raft
Updated 06/06/2021

Frame Subassembly [111.00]

Circular Saw

1. Cut all frame members 111.1A – 111.1D out of the 1x1 inch aluminum tube stock at the specified lengths with the 45-degree angle end conditions. The finished product will have a long and short side with the long side corresponding to the specified length.
2. Cut frame member 111.2A, 111.2B, and 111.2D out of the 1x1 inch aluminum tube stock at the specified lengths with all ends being flat.
3. Cut frame member 111.2C out of the 1x1.5 inch aluminum tube stock at a length of 37 inches with both end conditions being flat.
4. Cut frame member 111.3A - 111.3C out of the 1x1.5 inch aluminum angle stock at the specified lengths with all ends being flat.
5. Cute frame member 111.30 out of the 1x1 inch aluminum tube stock at the specified length and end condition.

Drill Press

1. Drill 4 holes in each 111.1A part at the specified locations and dimensions according to the part drawing for the motor mounts.
2. Drill 1 hole in each of the 111.1b parts at the dimensioned locations provided on the part drawing for drainage.
3. Drill 2 holes in part 111.2C at the specified location and dimension according to the part drawing for the U-bolt lift point.
4. Drill through the edge of part 111.2D to create the half circle female end of the flash pole mount member.
5. Drill through member 111.30 as the specified location and dimension according to the part drawing for the flash pole member.

Welding

1. Weld two of the 111.1A and two of the 111.1B parts together to create the main deck rectangular structure. The parts will mate together with the 45-degree angle end conditions and the two 111.1A and 111.1B should be opposite of each other.
2. Weld part 111.2C into the main deck frame with the length being parallel to the 111.1B members. The location of the member in between the two 111.1B frame components is specified in the frame assembly drawing.
3. Weld two of the 111.1C and two of the 111.1D parts together to create the lower deck rectangular structure. The parts will mate together with the 45-degree angle end conditions and the two 111.1C and 111.1D should be opposite of each other.

4. Weld the two 111.3B parts into the lower deck frame with the length being parallel to the 111.1D members. The location of the members in between the two 111.1D frame components is specified in the frame assembly drawing.
5. Weld the two 111.3C parts into the lower deck frame with the length being parallel to the 111.1D members. The location of the members in between the two 111.1D frame components is specified in the frame assembly drawing.
6. Weld two of the 111.2A vertical riser bars perpendicular to part 111.2B. This process will be repeated twice to yield two U shaped frame components.
7. Weld part 111.3A to the opposite side of the 111.2B member that the vertical riser bars are attached too. This process will be repeated on the second U shaped frame component.
8. Connect the lower deck to the main deck by welding 6 of the vertical riser bar (part 111.2A) in the specified location on the assembly drawing.
9. Weld the two upper deck members to the main deck of the frame. The location for the u-shaped frame components created in steps 6 and 7 are specified in the assembly drawing.
10. Weld the flash pole mount member to the main deck of the frame at the specified location in the frame assembly drawing.
11. Weld part 111.30 to the rear lateral member. The location of the member is specified in the frame assembly drawing.

Motor Attachment Subassembly [112.00]

Motor Mount [112.10]:

Circular Saw

1. Cut 112.31 out of 1.25 x 1.25 inch aluminum C channel at the specified length.
2. Cut 112.32 out of 2 x 1 inch aluminum C channel at the specified length.
3. Cut 112.33 out of 2 x 0.5 inch aluminum C channel at the specified length.

Mill

1. Face mill the C channel arms on part 112.33 down to 0.25 inches in length.

Drill Press

1. Drill the two holes in part 112.31 at the specified location and dimensions provided on the part drawing.
2. Drill four holes in part 112.33 at the specified location and dimensions provided on the part drawing.

Welding

1. Weld part 112.32 perpendicular to part 112.31 at the specified location provided in the assembly drawing.
2. Weld part 112.33 perpendicular to part 112.31 at the specified location provided in the assembly drawing.

Motor Arm [112.22]:

Circular Saw

1. Cut parts 112.41, 112.42, and 112.43 out of 1 inch aluminum round tube at the specified lengths.

Water Jet

1. Water jet parts 112.46 and 113.46 out of 0.125 inch thick aluminum sheet metal.

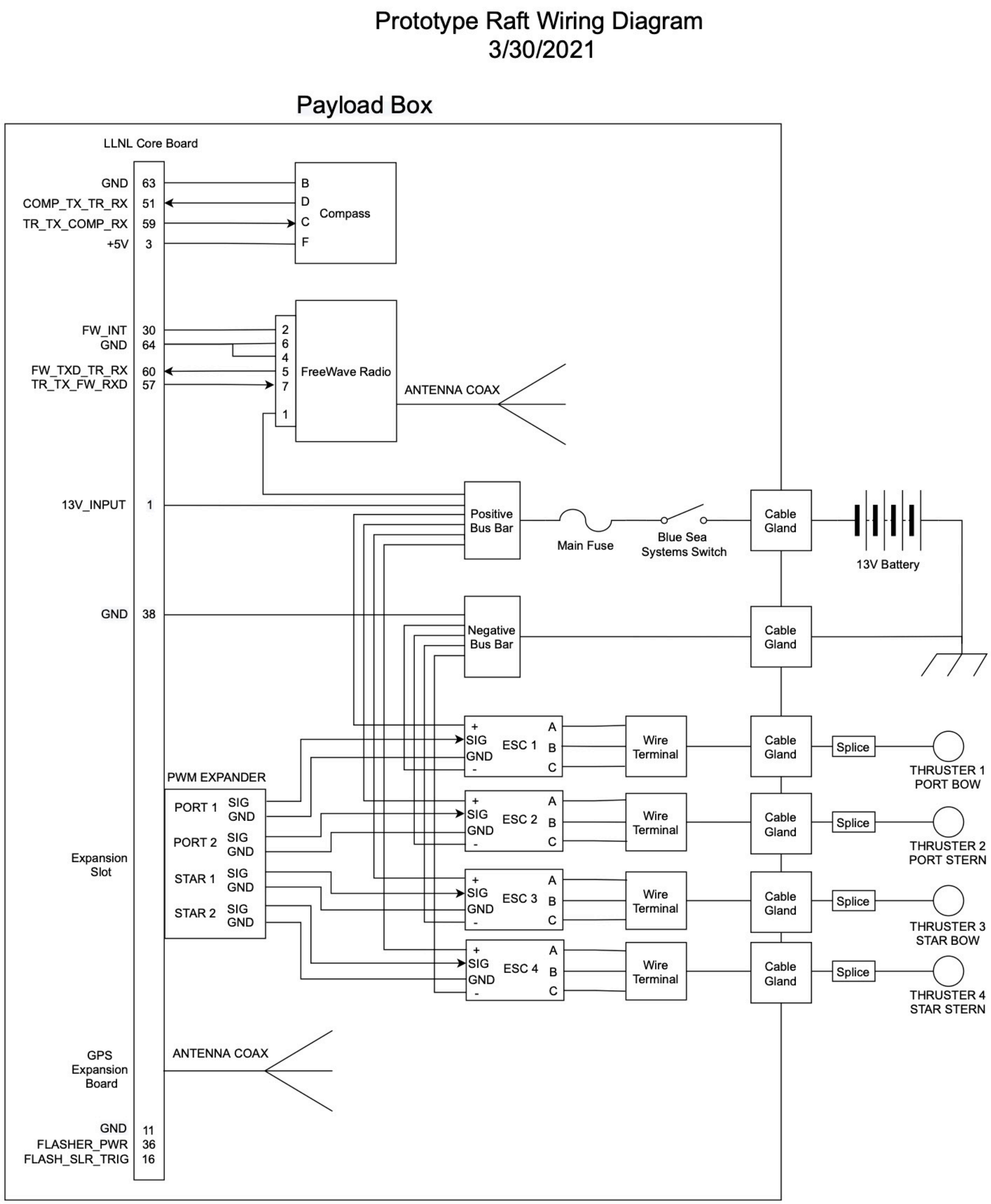
Drill Press

1. Drill ends of parts 112.41 and 112.43 to create the mating end conditions.
2. Drill out the specified hole in parts 112.46 and 113.46 at a 15-degree angle.

Welding

1. Weld part 122.41 perpendicular to 112.42 at the specified location provided in the assembly drawing.
2. Weld part 112.43 perpendicular to 112.42 at the specified location and angle provided in the assembly drawing.
3. Weld either part 112.46 or 113.46 to 112.42 for the respective motor arm sides at the location specified in the assembly drawing.

U. Appendix U: Payload Box Wiring Diagram



V. Appendix V: Final Project Budget

Design Stage	Vendor	Placed	Order Date	Description	Cost ($)
Prototype Manufacturing	Maravia	Luke	1/15/2021	Pontoons	$2089.00
Preliminary Testing	Home Depot	Kahye	1/26/2021	Fasteners for structural prototype	$80.43
Preliminary Testing	McMaster-Carr	Kahye	1/26/2021	Clips for structural prototype	$35.66
Preliminary Testing	Amazon	Kahye	1/26/2021	Scale for structural prototype	$10.99
Prototype Manufacturing	Blue Robotics	Jacob	2/10/2021	Thrusters + ESC's	$824.00
Prototype Manufacturing	PRW	Luke	2/16/2021	Metal for frame	$246.25
Prototype Manufacturing	McMaster-Carr	Luke	2/16/2021	Nuts + bolts + U-bolt for frame	$103.40
Prototype Manufacturing	Online Metals	Luke	2/16/2021	Metal for brackets and frame	$52.78
Prototype Manufacturing	MetalsDepot	Kahye	3/10/2021	Channel for motor mount	$31.68
Prototype Manufacturing	OnlineMetals	Kahye	3/10/2021	Channel, tube & sheet for motor mount	$183.57
Prototype Manufacturing	McMaster-Carr	Kahye	3/10/2021	Collar + end cap for motor arm	$74.32
Prototype Manufacturing	CES Santa Maria	Kahye	3/17/2021	Hoffman box + panel	$971.25
Prototype Manufacturing	Max-Gain Systems	Luke	4/02/2021	Flash pole	$55.93
Prototype Manufacturing	SeaLux	Luke	4/02/2021	Flash pole clips	$30.75
Prototype Manufacturing	McMaster-Carr	Kahye	4/12/2021	Fasteners for payload box hardware	$93.24
Prototype Manufacturing	Fastenal	Kahye	4/12/2021	Lock pins for flash pole	$14.04
Prototype Manufacturing	Fastenal	Kahye	4/19/2021	Fasteners for motor attachment	$40.65
Prototype Manufacturing	Xometry	Kahye	4/19/2021	Holders for motor mount	$245.70
Prototype Manufacturing	Amazon	Kahye	4/21/2021	Clips made by Amarine	$39.96
Prototype Manufacturing	Amazon	Andrew	4/22/2021	Miscellaneous electronic components	$223.63
Prototype Manufacturing	Battery Cables USA	Andrew	4/22/2021	Battery components	$23.50
Prototype Manufacturing	DigiKey	Andrew	4/22/2021	Fuse + wire connectors	$25.71
Prototype Manufacturing	NRS	Luke	4/23/2021	4' and 9' Straps for pontoons	$75.75
Prototype Manufacturing	Amazon	Andrew	4/26/2021	Amazon order for replacement thruster cable	$24.55
Prototype Testing	Testing	Kahye	5/14/2021	Rental test gear and facility fees.	$74.00
Total Cost					**$5670.74**

W. Appendix W: Design Verification Plan and Report (DVP&R)

DVP&R - Design Verification Plan (& Report)											
Project:	F52 - Research Raft	Sponsor:	Lawrence Livermore National Labs							Edit Date:	6/7/2021
TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
								Start date	Finish date		
1	Speed	We plan on taking the raft to a marine environment and measuring the speed of the raft at full speed.	Speed	5 ft/s	Marine Environment Transportation Speedometer	FP	Jacob	5/14/2021	5/14/2021	5 ft/s	While testing the raft traveled efficiently through the water and with a full battery moved relatively quickly. After analyzing the data, we found our raft was able to travel at speeds up to 5. ft/s. While promising, we do acknowledge the controlled environment this testing was conducted in. This will be fully covered in the report.
2	Stability	Once the final prototype is complete, we plan on deploying the raft into the lake that LLNL conducts testing in. In addition, we plan on deploying the raft to observe how stable it is in waves	Angle of raft w.r.t horizon	less than 90 degrees	LLNL Test Lake Marine Environment	FP	Luke	5/14/2021	5//14/21	Due to testing complications, we do not have numerical results, but the raft passed the test.	The boat that was going to be used to create the waves incurred mechanical problems so a formal test could not take place. While testing on the water for speed verification the raft was presented with waves from boats driving by. The waves were between 2-3 feet tall at a much higher frequency than normal use. By visual inspection we can conclude that the stability specification has been meet.
3	Waterproof	We plan to spray the payload box with water to ensure that it is watertight after modifications made for connectors	Water Ingress Pass / Fail	Pass	Water source (Hose hookup) Hose and high-pressure nozzle.	FP	Andrew	5/1/2021	5/12/2021	The waterproof test showed that there were minor leaks in the payload box, as a result it failed the test. However, see 'Notes on Testing' for further detail.	After we saw that water leaked through into the payload box, we bought a marine grade adhesive silicon sealant and sealed all the glands. Since the leaks were minor, we felt confident applying the sealant would waterproof the box.

4	Clip Retention	Using the structural prototype to simulate thruster forces through the arm on the clips. Various combinations of clips and arm tube dimensions were tested.	Force to remove arm from clip.	8 lbf	Fully built structural prototype, hand tools, elevated surface, and scale.	SP	Kahye	2/3/2021	2/3/2021	*See Table Below	The final selection was to go with two of the amarine clips. It was also observed that the original set up with only one holder was very unstable. The next design included two holders.
5	Field Assembly Time	With the final prototype, we will test how long it takes our team to assemble the raft. We want to make sure that the raft can be assembled quickly and easily	Assembly Time	5 minutes	Senior Project Room or other open space	FP	Kahye	5/13/2021	5/18/2021	The numerical results show an average of 45 seconds total to complete both processes of the field assembly time.	This test for this was done in an ideal and controlled environment. We anticipate that the total field assembly time will be larger when considering rough sea conditions and the unstable movement from being lifted on the crane. Regardless, we believe that the field assembly time will still be below the required specification of 5 minutes

Table for Clip Retention Results:

Clip	1" Diameter	3/4" Diameter
Sea Choice	3.31	2.57
Sea Choice (x2)	5.28	-
Amarine	5.89	3.07
Amarine (x2)	10.04	3.71
McMaster S.S clip (x2)	-	4.95
Cabinet Latch	12.17	-

X. Appendix X: Testing Procedures

Five test procedures were constructed for various components in the design as well as overall performance. The results from these tests are presented in the Design Verification chapter in the full report while the procedure is detailed below.

Test 1	Full System Speed Test
Test 2	Full System Stability Test
Test 3	Field Assembly Time
Test 4	Payload Box Waterproof Test
Test 5	Compass Calibration Test

Test 1 Procedure

Test Name: Speed Test
Purpose: The purpose of this test is to collect the data necessary to determine if the raft can move at and maintain the desired speed through the water.
Scope: This test will focus only on the speed of the raft and not on the ability of the raft to maintain or track position. These additional abilities are beyond the scope of our customer requirements.
Responsible Persons:

- **Primary:** Andrew Fleming
- **Secondary:** Jacob Davis
- **Tertiary:** Luke Vickerman
- **Safety Officer:** Kahye Yu – CPR/FA Trained

Testing Roles:

- 2 Kayakers – Luke and Kahye (with Jacob as alternate)
- 1 Controller – Andrew
- 1 Videographer (optional) – Jacob (with Luke as alternate)

Equipment:

- Raft Prototype
  - Frame
  - Pontoons
  - NRS Straps
  - Payload Box with critical components
  - Micro-USB Card
- Laptop, with Windows OS
- USB Connection for Raft Radios
- Raft Radios
- 100 ft of rope, split into two 50 ft sections
- Personal Vehicles – for raft and personnel transport
- Air Pump
- 2 Kayaks
- 2 PFDs
- 2 Paddles
- Personal Radios for watercraft and operation communication
- First Aid Kit

Hazards:

- Operation near water could raise the risk of aquatic accidents.
  - Control to the raft will not be enabled until the raft is in the water to prevent risk of injury due to thruster rotation and to prevent thruster damage.
  - When active in the water, no person shall move within 5 ft of the raft, to prevent possible injury, unless necessary for an emergency. This includes persons on watercraft.
  - Persons kayaking in the water will take care to avoid the raft and warn other boaters of the presence of the raft.
- Electric components near water could cause shock.
  - Main power to electrical components will remain disconnected until necessary.
  - Main power to electrical components will be disconnected as soon as possible at the conclusion of the test.
  - Waterproof payload box will not be opened once the raft is in/on the water.

- Improper lifting can cause stress and strain injuries.
    - When lifting, exercise proper lifting protocol.
- This test protocol requires three people to execute and recommends 4+ people.
    - Failure to adhere to this recommendation could result in injury.

PPE Requirements:

- Life vests for all persons near and entering the water.
- COVID: Face coverings for all people present.
- Safety glasses for kayakers.

Facility: Lake Nacimiento – East End Public Boat Launch

Safety Information:

- Nearest Urgent Care:
  MedPost Urgent Care of Paso Robles
  500 1st Street, Paso Robles, CA 93446
  (805) 226-4222
- Nearest Emergency:
  Twin Cities Community Hospital
  1100 Las Tablas Rd, Templeton, CA 93456
  (805) 434-500
- Local Contact Phone Number: (805) 238-3256

Procedure:

Data Collection:

1. Unload the raft from a vehicle and place level on the ground.
2. Open the payload box and verify that the micro-USB data card is installed properly.
3. Close and seal the payload box.
4. Inflate the pontoons using an air pump and set one pontoon on either side of the raft.
5. Lifting one side of the raft at a time and taking care to avoid scraping the pontoons along the ground, move the pontoons under the wings on either side of the raft main deck.
6. Center the raft within the flat portions of the inflated pontoons, taking care to avoid scraping the pontoons.
7. Secure the pontoons to the frame using the NRS Straps, threading the straps around the corner of the raft, and through the D-rings on the pontoons.
8. Using both lengths of rope, secure the raft so that it does not drift on the water during setup.
9. With at least two people, lift the raft at least two feet above the ground.
    a. Improper lifting can cause back strain. Exercise proper lifting protocol.
10. Two people should put on PPE and enter kayaks.
    a. PPE includes, but is not limited to, a PFD and safety glasses.
    b. These people should each hold on to a section of the rope attached to the raft.
    c. Each test member on the water should have a personal radio with them.
11. Gently move the raft into the water.
    a. Care must be taken to avoid dropping the raft onto the surface of the water or on the ground.
12. Once the raft is in the water, move the motor arms into their clipped position.
13. All test members must exit the water or be seated in a kayak before the thrusters are started.
    a. One of the team members in a kayak should turn on the main power to the raft.
    b. This team member should take care when reaching out of the kayak.

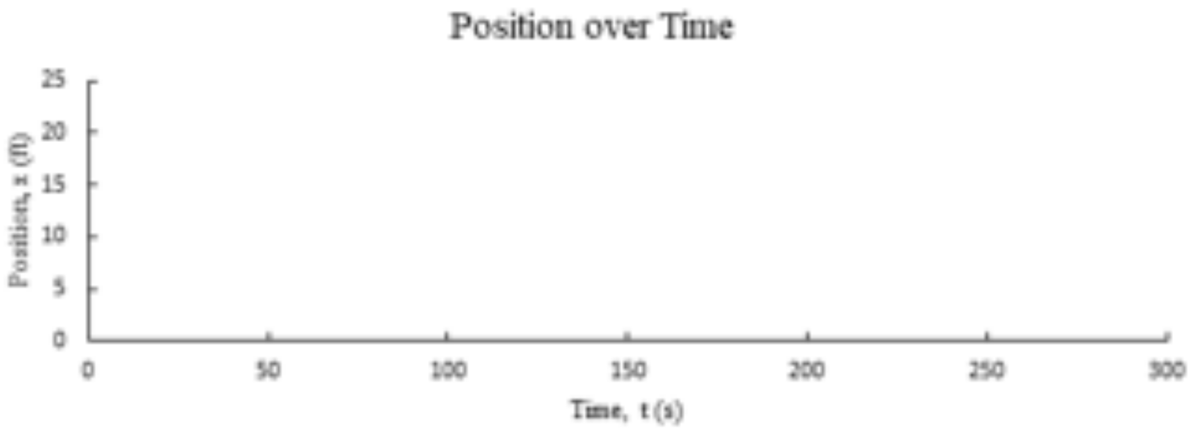
14. Open the laptop and connect the raft radio.
    a. This person will not be in a kayak.
15. Start the raft control software, verify all critical components are functioning, and verify the raft is responding to commands.
    a. These commands include:
        i. Waypoint navigation;
        ii. Manual navigation, including turning in both directions, forward, and reverse;
        iii. Motion override and stop.
16. Start data collection.
    a. This includes the location data onboard the raft, velocity data within the raft control software, and video recording of the raft in motion from the shore.
17. Before moving the raft, ensure both sections of rope are untied from the raft.
    a. These sections should be kept with the kayakers, to restrain and tow the raft in the unlikely event of communication interruption or electrical failure.
    b. During the testing, the raft should remain untethered, so that it does not drag team members in kayaks along behind. There ropes could also cause water hazards when dragged behind the raft, especially if they get near the thrusters.
18. Move the raft away from shore using the thrusters, and orient it so that it has a clear straight path for 500 ft.
19. Direct the raft to move in a straight line in the bow direction for 500 ft, using half the distance to accelerate to 6 ft/s, and the rest of the distance to travel at that constant speed.
    a. For the purposes of our testing, a small drift will not negatively affect data collection.
    b. Any drift that needs to be corrected will be performed with power alterations.
20. Bring the raft to a halt.
21. Direct the raft to move in a straight line in the stern direction, with the thrusters in reverse, for 500 ft, again, using the same speed profile and magnitude.
22. Bring the raft to a halt.
23. Stop data collection.
24. Repeat steps 17 through 22 twice more, for a total of three repetitions.
    a. Wait 2 minutes between repetitions, to help differentiate each repetition in the data.
    b. The raft should be moved as little as possible between repetitions, to better differentiate between each repetition in the data.

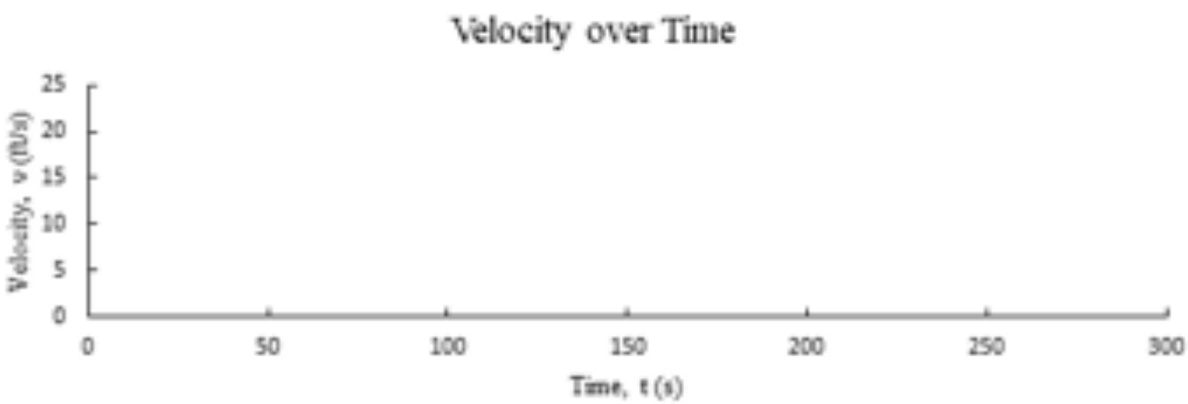
Data Analysis: Data analysis steps should take place after completing on-site testing, but before leaving the test site.

1. Remove the micro-USB card and insert it into a laptop.
2. Open the data files on the card and copy the data files pertaining to the day's testing to the hard drive.
3. Import the data into Excel for analysis.
4. Convert latitude and longitude positional data from each time step into a distance travelled.
5. Use the timestamp information and the positional data in an instantaneous velocity calculation to determine velocity over time.
6. From the instantaneous velocity data over time, determine the top speed of the raft.
    a. Top speed is defined as the highest possible linear velocity that the raft can maintain for over a continuous period of 5 seconds or 25 feet of travel, whichever is longer.

Results:
The raft should take two or three trips, over a similar distance and acceleration profile, if possible. This will help increase the amount of data available for analysis.
This test will yield position data of the raft over time, at discrete time intervals. This data can be input into the fundamental equation for a derivative to determine the instantaneous velocity as a function of time. This data is used to verify the top speed of the raft, so that it meets specifications. The velocity data over time is useful, but the criteria for the test are a pass/fail, with a threshold of 5 ft/s.

Test Date(s): ____/_____/_____
Test Results:





TEST SPECIFICATION	PASS	FAIL
Raft maximum speed is at least 5 ft/s		

Performed By: ____________________

Test 2 Procedure

Test Name: Stability Test
Purpose: Evaluate raft performance in varying wave conditions to ensure stability in specified ocean environment.
Scope: The normal operating wave conditions have been specified as 3 feet in height at a frequency of 30-40 feet.
Responsible Persons:

- **Primary:** Andrew Fleming
- **Secondary:** Jacob Davis
- **Tertiary:** Luke Vickerman
- **Safety Officer:** Kahye Yu – CPR/FA Trained

Testing Roles:

- 2 Kayakers – Luke and Kahye (with Jacob as alternate)
- 1 Controller – Andrew
- 1 Videographer (optional) – Jacob (with Luke as alternate)

Equipment:

- Raft Prototype
  - Frame
  - Pontoons
  - NRS Straps
  - Payload Box with critical components
  - Micro-USB Card
- Laptop, with Windows OS
- USB Connection for Raft Radios
- Raft Radios
- 100 ft of rope, split into two 50 ft sections
- Personal Vehicles – for raft and personnel transport
- Air Pump
- 2 Kayaks
- 2 PFDs
- 2 Paddles
- Personal Radios for watercraft and operation communication
- First Aid Kit

Hazards:

- Operation near water could raise the risk of aquatic accidents.
  - Control to the raft will not be enabled until the raft is in the water to prevent risk of injury due to thruster rotation and to prevent thruster damage.
  - When active in the water, no person shall move within 5 ft of the raft, to prevent possible injury, unless necessary for an emergency. This includes persons on watercraft.
  - Persons kayaking in the water will take care to avoid the raft and warn other boaters of the presence of the raft.

- Electric components near water could cause shock.
    - Main power to electrical components will remain disconnected until necessary.
    - Main power to electrical components will be disconnected as soon as possible at the conclusion of the test.
- Improper lifting can cause stress and strain injuries.
    - When lifting, exercise proper lifting protocol.
- This test protocol requires three people to execute and recommends 4+ people.
    - Failure to adhere to this recommendation could result in injury.
- This test protocol involves operation near an operating power boat.
    - It is recommended that the power boat travels over 100 feet away from the shore to allow for kayakers and the raft to navigate safely near the shore.

PPE Requirements:

- Life vests for all persons near and entering the water.
- COVID: Face coverings for all people present.
- Safety glasses for kayakers.

Facility: Lake Nacimiento – East End Public Boat Launch

Safety Information:

- Nearest Urgent Care:

    MedPost Urgent Care of Paso Robles
    500 1st Street, Paso Robles, CA 93446
    (805) 226-4222
- Nearest Emergency:

    Twin Cities Community Hospital
    1100 Las Tablas Rd, Templeton, CA 93456
    (805) 434-5000

Procedure:

Data Collection:

1) Unload the raft components from a vehicle and place level on the ground.
2) Open the payload box and verify that the micro-USB data card is installed properly.
3) Close and seal the payload box.
4) Inflate the pontoons using an air pump and set one pontoon on either side of the raft.
5) Lifting one side of the frame at a time and taking care to avoid scraping the pontoons along the ground, move the pontoons under the wings on either side of the raft main deck.
6) Center the frame within the flat portions of the inflated pontoons, taking care to avoid scraping the pontoons. The center of the pontoons should align with the lift U-bolt.
7) Secure the pontoons to the frame using the NRS Straps, threading the straps around the corner of the raft, and through the D-rings on the pontoons.
8) With at least two people, lift the raft at least two feet above the ground.
9) Gently move the raft into the water.
    a. Care must be taken to avoid dropping the raft onto the surface of the water.
10) Once the raft is in the water, move the motor arms into their clipped position.
11) Using rope tie up the raft to the dock such that it does not drift away.

12) Two people should put on PPE and enter kayaks.
    a. PPE includes, but is not limited to, a PFD and safety glasses.
    b. These people should each have a 50-foot section of rope in case of malfunction.
    c. Each test member on the water should have a personal radio with them.
13) All test members must exit the water or be seated in a kayak before the thrusters are started.
    a. One of the team members staying on shore should turn on the main power to the raft from the dock.
14) Open the laptop and connect the raft radio.
15) Start the raft control software, verify all critical components are functioning, and verify the raft is responding to commands.
16) Start data collection.
17) Before moving the raft, ensure both sections of rope are untied from the raft.
    a. These sections should be kept with the kayakers, to restrain and tow the raft in the unlikely event of communication interruption or electrical failure.
18) Untie the raft and move it away from shore.
    a. Make sure data collection is still taking place.
19) Send the raft to a location 50 feet offshore and have it hold position.
20) The power boat will pass by at a minimum distance of 100 feet from shore 10 times.
    a. Each pass by should be spaced out by a minimum of 1 minute so that data analysis is clear.
    b. Each pass with the larger boat should increase the wake size until the righting angle is 12 degrees. Depending on the boat capacity this angle may have to be calculated from the height and wave frequency after testing.
21) Return the raft to the launch ramp and tie to the dock using rope.
22) Stop data collection.
23) A team member on shore will turn off the main power.
24) Move the raft near the launch ramp while maintaining a minimum water depth of 2 feet.
25) 4 team members will lift the raft out of the water and carry it to a flat surface and lower it gently allowing the motor arms to dislodge from the clips.
26) Disassemble the raft and pack into the transportation vehicle.

Data Analysis: Data analysis steps should take place after completing on-site testing.

1) Remove the micro-USB card and insert it into a laptop.
2) Open the data files on the card and copy the data files pertaining to the day's testing to the hard drive.
3) Import the data into Excel for analysis.
4) Separate the data from each test into a different table taking sections of 60 seconds centered around the dynamic motion.
5) Preform righting angle calculation if need by and fill out the pass/fail criteria.

Results: The normal operating wave conditions have been specified as waves 3 feet in height at a frequency of approximately 30-40 feet. The desired performance we have specified would be to maintain stability in 5-foot rolling waves at a frequency of 25 feet. In these conditions the average "righting angle" is calculated to be 11.31 degrees up from horizontal. The desired results from this test would be avoid flipping in righting angles of at least 12 degrees. Readings are recorded every second and the boat will pass by the raft 10 times. An estimate of 20 readings of dynamic motion will be produced per pass.

Test Date(s): ____/____/_____

Test Results:
The control test results table is shown below. Each pass by the larger boat will be documented in a similar table. Elevation data will provide detail into the specific wave height and frequency can be calculated form the period between maximum elevations in the dynamic testing.

Control Test Results

	Location			**Rotation**			
Time	**Longitude**	**Latitude**	**Elevation**	**Heading**	**Roll**	**Tilt**	**Flip**
1							[Y/N]
...							
60							

Performed By: ____________________

Test 3 Procedure

Test Name: Field Assembly Time Test
Purpose: The purpose of this test is to record the amount of time it takes to assemble the raft for deployment.
Scope: This test will give us an average time for field assembly that will be compared to the desired field assembly time specification given to us from our sponsor.
Equipment:
- Timer
- Table

Hazards and Test Safety:

Safety Concern	Response
Pinch points while clipping in motor arms	Ensure user keeps hands away from clips and use bottom of motor arm to set arm into clip
Lifting the raft	Ensure at least 1 person is lifting for every 40 lbs

PPE Requirements:
- COVID: Facemasks worn at all time

Facility: High bay or senior project room 197-110

Procedure:
1. Start the timer and begin assembling the light pole
   a. Remove the pole from storage position, insert it into the holder, insert the pins and connect it to its respective power source.
   b. Once complete, stop the time and record it down on the table.
2. Transfer the raft onto an elevated surface.
3. Start the timer and begin positioning the motor attachments such they're in travel/operating mode.
   a. Once all the motor attachments are in travel mode, stop the time and record it on the table.

Results: Pass Criteria, Fail Criteria, Number of samples to test
To pass, the total average assembly time (light pole time + motor attachment time) must be 5 minutes or less. Therefore, if the total average assembly time is greater than 5 minutes, this is deemed a failure of the criteria. To get a good average of total assembly time, the test will be done a total of 5 times

Test Date(s): ___/___/___
Test Results:

Run	Lighpole Time [min:sec]	Motor Time [min:sec]	Total Time [min:sec]
1			
2			
3			
4			
5			

Average Total Time	

Performed By: __________

Test 4 Procedure

Test Name: Payload Box Waterproof Test

Purpose: The purpose of this test is to ensure that the Payload box is waterproof after it is modified. The Hoffman payload box is rated to IP66 waterproof standards by the manufacturer, but we will modify it to install cable glands that waterproof through-box electrical wiring. This test will ensure that it is safe to install electrical components within the box and perform other testing on the water.

Scope: This test will test whether the payload box is waterproof after cable glands are installed. We cannot perform IP66 standards testing, so we will instead spray the box with water from a hose and check that no water enters the box.

Equipment:
- Modified payload box with connectors installed
- Hose hookup
- Garden hose
- High pressure hose nozzle
- Cobalt chloride test strips / cloth
- Paper towels
- Scotch tape

Hazards:
- Jets of water can cause injury to eyes if it is sprayed in one's face.
- Handling cobalt chloride paper with bare skin can cause irritation

PPE Requirements:
- Closed toed shoes
- Safety glasses
- Nitrile gloves
- COVID: Facemasks

Facility: Hangar Apron

Procedure:
1. Unlatch and open the payload box lid. Remove all electronics from Payload Box. Ensure that waterproof connectors are installed.
2. Wearing nitrile gloves, remove cobalt chloride strips from sealed container. Using scotch tape, attach strips to the interior walls of the box, specifically around and below the waterproof connectors. Be sure to only tape over the ends of the strips and leave most of the strip exposed to the air.
3. Lay cobalt chloride cloth (if using) or paper towels on the floor of the payload box, making sure they extend to all edges.
4. Close and latch payload box, ensuring that the lid gasket is free of debris. Place the payload box in an open area where water can drain away from it.
5. Connect garden hose to hose hookup and install the high-pressure hose nozzle. Holding the hose in a direction away from others, turn on the water to high.

6. Spray the payload box from 5 feet away for 60 seconds, making sure to spray the area around each through-box connector and around the lid. Turn off the water.
7. Remove the high-pressure nozzle. Turn on the water and using just the hose end, spray the areas around the through-box connectors with water for 60 seconds. Turn off the water. Remove and store hose.
8. Dry the top of the payload box and the edges of the lid with water before opening the box to ensure no exterior water enters when it is opened.
9. Open the payload box and inspect the interior for water, paying close attention to areas around the connectors for water droplets or discoloration of cobalt chloride strips. Also check the floors for any drops or pools of water.
10. Remove and dispose of cobalt strips and paper towels. Dry the outside of the payload box and store. Clean up testing area

Results:
Pass Criteria: If, upon visual inspection of the box interior, no water is found and all cobalt chloride strips within the box are blue, then the box waterproofing meets requirements.

Fail Criteria: If, upon visual inspection of the box interior, pools or droplets of water are found, or any cobalt chloride strips have changed color from blue, then the box waterproofing does not meet requirements.

If the payload box does not meet waterproofing requirements specified above, then steps will be taken to seal locations of water ingress and the test will be performed again under the same procedures

Test Date(s): ___/___/___

Test Results:

Performed By: _________

Test 5 Procedure

Test Name: Compass Calibration Test

Purpose: The focus of this test is to determine the precision and accuracy of the compass data from the LLNL control board.

Scope: The scope of this test will be limited to the compass instrumentation on the LLNL control board. The data is confounded with the control board itself, and this test will determine bias and expected precision from both components as a single system.

Equipment:

- LLNL Control Board
- LLNL Compass
- LLNL Radio
- Laptop
- Angle Finder
- Table
- Flat Board
- Varying Thickness Blocks
- Power Source

Hazards:

- Pinch points
- Heavy Equipment
- Electrical Shock

PPE Requirements:

- COVID: Facemasks worn at all times
- Gloves worn by the person who is holding the block
- Electronics should not be touched directly when connected to a power supply

Facility: 197-110

Procedure:

1) Lay flat board across the table.
2) Place and constrain the angle finder to the flat board, using the table surface as a datum.
3) Place the control board and radio on the tabletop and place the compass on the flat plate.
4) Connect the radio, control board, compass, and power source together, using the applicable wiring diagrams.
5) Connect the control board to the laptop and open the applicable data collection software.
6) Begin data collection.
7) Wait for 10 seconds.
8) Insert the block under the flat plate, such that the angle increases by 2 degrees.
9) Hold the block in position to maintain the angle, for at least 5 seconds.
10) Repeat steps 8 and 9 until the plate has been held at 20 degrees from the horizontal.

11) End data collection.
12) Repeat steps 7 through 11, starting at 20 degrees from the horizontal and decreasing 2 degrees every incrementation.
13) Repeat steps 6 to 12.

Results:

There is not pass or fail criteria, barring an extreme failure of parts. The goal is to collect data and better understand the bias and precision of the angle measurements from the control board and compass system.

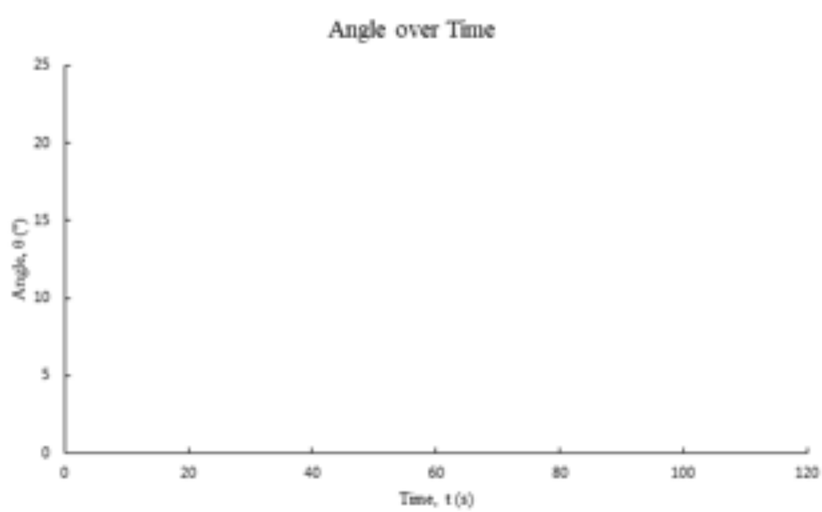
For the final raft operation, the normal operating wave conditions have been specified as three-foot waves spaced 30 to 40 feet apart. The desired performance we have specified would be to maintain stability in five-foot rolling waves, with peaks 25 feet apart. In these conditions, we estimate the righting angle to be 11.31 degrees up from horizontal.

The desired results from this test would be a plot of input angles over time and a plot of measured angles over time, on the same set of axes. We could use this plot to correct for bias. We can also use the raw data, to determine if the precision is better that our input precision. This would tell us how to interpret the data from the control board.

The test procedure tests angles from zero to twenty degrees, in both the ascending and descending direction, in case a different bias exists in different directions. The twice repetition of the data will help to eliminate stray inputs from the test.

Test Date(s): ____/_____/_____

Test Results:



Performed By: ____________________

Y. Appendix Y: Speed Test Data Sheet

Time	Position Data		ϕ	λ	Δϕ	Δλ	a	c	Distance	Distance
	Latitude	Longitude	(Rad)	(Rad)	(Rad)	(Rad)			(mi)	(ft)
Run 1										
1:35:27 PM	35.7621755	-120.9015973	0.62416771	-2.11013094	--	--	--	--	--	--
1:35:28 PM	35.7621738	-120.9015997	0.62416768	-2.11013099	-2.96706E-08	-4.18879E-08	5.08915E-16	4.51183E-08	0.000179	0.94
1:35:29 PM	35.7621697	-120.9016035	0.624167609	-2.11013105	-7.15585E-08	-6.63225E-08	2.00423E-15	8.95373E-08	0.000354	1.87
1:35:30 PM	35.7621650	-120.9016083	0.62416753	-2.11013114	-8.20305E-08	-8.37758E-08	2.83757E-15	1.06538E-07	0.000422	2.23
1:35:31 PM	35.7621557	-120.9016115	0.62416736	-2.11013119	-1.62316E-07	-5.58505E-08	7.10006E-15	1.68524E-07	0.000667	3.52
1:35:32 PM	35.7621433	-120.9016127	0.62416715	-2.11013121	-2.16421E-07	-2.0944E-08	1.17817E-14	2.17087E-07	0.000859	4.54
1:35:33 PM	35.7621313	-120.9016097	0.62416694	-2.11013116	-2.0944E-07	5.23599E-08	1.14175E-14	2.13706E-07	0.000846	4.47
1:35:34 PM	35.7621195	-120.9016025	0.62416673	-2.11013103	-2.05949E-07	1.25664E-07	1.32032E-14	2.2981E-07	0.000910	4.80
1:35:35 PM	35.7621092	-120.9015938	0.62416655	-2.11013088	-1.79769E-07	1.51844E-07	1.18746E-14	2.17941E-07	0.000863	4.56
1:35:36 PM	35.7620992	-120.9015842	0.62416638	-2.11013072	-1.74533E-07	1.67552E-07	1.22367E-14	2.21239E-07	0.000876	4.62
1:35:37 PM	35.7620902	-120.9015742	0.62416622	-2.11013054	-1.5708E-07	1.74533E-07	1.11829E-14	2.11498E-07	0.000837	4.42
1:35:38 PM	35.7620807	-120.9015632	0.62416606	-2.11013035	-1.65806E-07	1.91986E-07	1.29404E-14	2.27511E-07	0.000901	4.76
1:35:39 PM	35.7620723	-120.9015513	0.62416591	-2.11013014	-1.46608E-07	2.07694E-07	1.24743E-14	2.23377E-07	0.000884	4.67
1:35:40 PM	35.7620653	-120.9015370	0.62416579	-2.11012989	-1.22173E-07	2.49582E-07	1.39855E-14	2.36521E-07	0.000936	4.94
1:35:41 PM	35.7620598	-120.9015217	0.62416569	-2.11012962	-9.59931E-08	2.67035E-07	1.40419E-14	2.36997E-07	0.000938	4.95
1:35:42 PM	35.7620540	-120.9015062	0.62416559	-2.11012935	-1.01229E-07	2.70526E-07	1.46089E-14	2.41735E-07	0.000957	5.05
1:35:43 PM	35.7620483	-120.9014918	0.62416549	-2.11012910	-9.94838E-08	2.51327E-07	1.28721E-14	2.26911E-07	0.000898	4.74
1:35:44 PM	35.7620432	-120.9014770	0.62416540	-2.11012884	-8.90118E-08	2.58309E-07	1.29643E-14	2.27722E-07	0.000902	4.76
1:35:45 PM	35.7620387	-120.9014603	0.62416532	-2.11012855	-7.85398E-08	2.9147E-07	1.55268E-14	2.49213E-07	0.000987	5.21
1:35:46 PM	35.7620360	-120.9014443	0.62416528	-2.11012827	-4.71239E-08	2.79253E-07	1.3392E-14	2.31448E-07	0.000916	4.84
1:35:47 PM	35.7620342	-120.9014292	0.62416524	-2.11012801	-3.14159E-08	2.63545E-07	1.16801E-14	2.16149E-07	0.000856	4.52
1:35:48 PM	35.7620333	-120.9014135	0.62416523	-2.11012774	-1.5708E-08	2.74017E-07	1.24217E-14	2.22905E-07	0.000882	4.66
1:35:49 PM	35.7620325	-120.9013970	0.62416521	-2.11012745	-1.39626E-08	2.87979E-07	1.37005E-14	2.34098E-07	0.000927	4.89
1:35:50 PM	35.7620317	-120.9013800	0.62416520	-2.11012715	-1.39626E-08	2.96706E-07	1.45404E-14	2.41167E-07	0.000955	5.04
1:35:51 PM	35.7620317	-120.9013630	0.62416520	-2.11012685	0	2.96706E-07	1.44916E-14	2.40762E-07	0.000953	5.03
1:35:52 PM	35.7620325	-120.9013462	0.62416521	-2.11012656	1.39626E-08	2.93215E-07	1.42014E-14	2.38339E-07	0.000944	4.98
1:35:53 PM	35.7620337	-120.9013298	0.62416524	-2.11012628	2.0944E-08	2.86234E-07	1.35964E-14	2.33207E-07	0.000923	4.87
1:35:54 PM	35.7620345	-120.9013140	0.62416525	-2.11012600	1.39626E-08	2.75762E-07	1.25667E-14	2.24203E-07	0.000888	4.69
1:35:55 PM	35.7620358	-120.9012975	0.62416527	-2.11012571	2.26893E-08	2.87979E-07	1.37804E-14	2.3478E-07	0.000929	4.91
1:35:56 PM	35.7620377	-120.9012813	0.62416531	-2.11012543	3.31613E-08	2.82743E-07	1.34347E-14	2.31817E-07	0.000918	4.85
1:35:57 PM	35.7620402	-120.9012670	0.62416535	-2.11012518	4.36332E-08	2.49582E-07	1.07299E-14	2.07171E-07	0.000820	4.33
1:35:58 PM	35.7620428	-120.9012518	0.62416539	-2.11012491	4.53786E-08	2.6529E-07	1.21001E-14	2.20001E-07	0.000871	4.60
1:35:59 PM	35.7620457	-120.9012365	0.62416544	-2.11012465	5.06145E-08	2.67035E-07	1.23787E-14	2.22519E-07	0.000881	4.65
1:36:00 PM	35.7620495	-120.9012215	0.62416551	-2.11012438	6.63225E-08	2.61799E-07	1.23821E-14	2.2255E-07	0.000881	4.65
1:36:01 PM	35.7620530	-120.9012063	0.62416557	-2.11012412	6.10865E-08	2.6529E-07	1.25182E-14	2.23769E-07	0.000886	4.68
1:36:02 PM	35.7620568	-120.9011912	0.62416564	-2.11012386	6.63225E-08	2.63545E-07	1.2533E-14	2.23902E-07	0.000886	4.68
1:36:03 PM	35.7620610	-120.9011760	0.62416571	-2.11012359	7.33038E-08	2.6529E-07	1.29286E-14	2.27408E-07	0.000900	4.75
1:36:04 PM	35.7620652	-120.9011608	0.62416579	-2.11012333	7.33038E-08	2.6529E-07	1.29286E-14	2.27408E-07	0.000900	4.75
1:36:05 PM	35.7620695	-120.9011460	0.62416586	-2.11012307	7.50492E-08	2.58309E-07	1.23916E-14	2.22636E-07	0.000881	4.65
1:36:06 PM	35.7620737	-120.9011317	0.62416593	-2.11012282	7.33038E-08	2.49582E-07	1.15973E-14	2.15382E-07	0.000853	4.50
1:36:07 PM	35.7620780	-120.9011165	0.62416601	-2.11012255	7.50492E-08	2.6529E-07	1.29934E-14	2.27977E-07	0.000903	4.77
1:36:08 PM	35.7620817	-120.9011013	0.62416607	-2.11012229	6.45772E-08	2.6529E-07	1.26278E-14	2.24747E-07	0.000890	4.70
1:36:09 PM	35.7620858	-120.9010865	0.62416614	-2.11012203	7.15585E-08	2.58309E-07	1.22637E-14	2.21483E-07	0.000877	4.63
1:36:10 PM	35.7620900	-120.9010713	0.62416622	-2.11012176	7.33038E-08	2.6529E-07	1.29286E-14	2.27408E-07	0.000900	4.75
1:36:11 PM	35.7620942	-120.9010563	0.62416629	-2.11012150	7.33038E-08	2.61799E-07	1.26258E-14	2.24729E-07	0.000890	4.70
1:36:12 PM	35.7620980	-120.9010413	0.62416636	-2.11012124	6.63225E-08	2.61799E-07	1.23821E-14	2.22549E-07	0.000881	4.65
1:36:13 PM	35.7621020	-120.9010267	0.62416643	-2.11012098	6.98132E-08	2.54818E-07	1.19072E-14	2.1824E-07	0.000864	4.56
1:36:14 PM	35.7621058	-120.9010110	0.62416649	-2.11012071	6.63225E-08	2.74017E-07	1.34597E-14	2.32032E-07	0.000919	4.85
1:36:15 PM	35.7621095	-120.9009957	0.62416656	-2.11012044	6.45772E-08	2.67035E-07	1.27808E-14	2.26104E-07	0.000895	4.73
1:36:16 PM	35.7621135	-120.9009805	0.62416663	-2.11012018	6.98132E-08	2.6529E-07	1.28037E-14	2.26307E-07	0.000896	4.73
1:36:17 PM	35.7621175	-120.9009655	0.62416670	-2.11011992	6.98132E-08	2.61799E-07	1.25009E-14	2.23615E-07	0.000885	4.67
1:36:18 PM	35.7621215	-120.9009498	0.62416677	-2.11011964	6.98132E-08	2.74017E-07	1.35785E-14	2.33053E-07	0.000923	4.87
1:36:19 PM	35.7621262	-120.9009342	0.62416685	-2.11011937	8.20305E-08	2.72271E-07	1.38853E-14	2.35672E-07	0.000933	4.93
1:36:20 PM	35.7621305	-120.9009192	0.62416692	-2.11011911	7.50492E-08	2.61799E-07	1.26905E-14	2.25304E-07	0.000892	4.71
1:36:21 PM	35.7621352	-120.9009042	0.62416701	-2.11011885	8.20305E-08	2.61799E-07	1.29646E-14	2.27725E-07	0.000902	4.76
1:36:22 PM	35.7621395	-120.9008887	0.62416708	-2.11011858	7.50492E-08	2.70526E-07	1.34552E-14	2.31993E-07	0.000918	4.85
1:36:23 PM	35.7621433	-120.9008733	0.62416715	-2.11011831	6.63225E-08	2.68781E-07	1.29918E-14	2.27963E-07	0.000903	4.77
1:36:24 PM	35.7621475	-120.9008585	0.62416722	-2.11011805	7.33038E-08	2.58309E-07	1.23269E-14	2.22053E-07	0.000879	4.64
1:36:25 PM	35.7621518	-120.9008437	0.62416730	-2.11011779	7.50492E-08	2.58309E-07	1.23916E-14	2.22635E-07	0.000881	4.65
1:36:26 PM	35.7621562	-120.9008283	0.62416737	-2.11011752	7.67945E-08	2.68781E-07	1.33665E-14	2.31227E-07	0.000915	4.83
1:36:27 PM	35.7621603	-120.9008132	0.62416744	-2.11011726	7.15585E-08	2.63545E-07	1.27135E-14	2.25508E-07	0.000893	4.71
1:36:28 PM	35.7621643	-120.9007985	0.62416751	-2.11011700	6.98132E-08	2.56563E-07	1.20541E-14	2.19582E-07	0.000869	4.59
1:36:29 PM	35.7621685	-120.9007837	0.62416759	-2.11011674	7.33038E-08	2.58309E-07	1.23269E-14	2.22053E-07	0.000879	4.64
1:36:30 PM	35.7621725	-120.9007683	0.62416766	-2.11011648	6.98132E-08	2.68781E-07	1.31106E-14	2.29003E-07	0.000907	4.79
1:36:31 PM	35.7621770	-120.9007537	0.62416774	-2.11011622	7.85398E-08	2.54818E-07	1.22308E-14	2.21186E-07	0.000876	4.62
1:36:32 PM	35.7621812	-120.9007392	0.62416781	-2.11011597	7.33038E-08	2.53073E-07	1.18861E-14	2.18047E-07	0.000863	4.56
1:36:33 PM	35.7621855	-120.9007243	0.62416788	-2.11011571	7.50492E-08	2.60054E-07	1.25405E-14	2.23969E-07	0.000887	4.68
1:36:34 PM	35.7621897	-120.9007093	0.62416796	-2.11011545	7.33038E-08	2.61799E-07	1.26257E-14	2.24729E-07	0.000890	4.70
1:36:35 PM	35.7621935	-120.9006947	0.62416802	-2.11011519	6.63225E-08	2.54818E-07	1.17883E-14	2.17148E-07	0.000860	4.54
1:36:36 PM	35.7621973	-120.9006800	0.62416809	-2.11011493	6.63225E-08	2.56563E-07	1.19353E-14	2.18497E-07	0.000865	4.57
1:36:37 PM	35.7622012	-120.9006643	0.62416816	-2.11011466	6.80678E-08	2.74017E-07	1.35183E-14	2.32536E-07	0.000921	4.86
1:36:38 PM	35.7622055	-120.9006488	0.62416823	-2.11011439	7.50492E-08	2.70526E-07	1.34552E-14	2.31993E-07	0.000918	4.85
1:36:39 PM	35.7622088	-120.9006335	0.62416829	-2.11011412	5.75959E-08	2.67035E-07	1.25675E-14	2.2421E-07	0.000888	4.69
1:36:40 PM	35.7622127	-120.9006187	0.62416836	-2.11011386	6.80678E-08	2.58309E-07	1.21418E-14	2.2038E-07	0.000872	4.61
1:36:41 PM	35.7622163	-120.9006033	0.62416842	-2.11011360	6.28319E-08	2.68781E-07	1.28791E-14	2.26972E-07	0.000899	4.74
1:36:42 PM	35.7622197	-120.9005877	0.62416848	-2.11011332	5.93412E-08	2.72271E-07	1.30833E-14	2.28765E-07	0.000906	4.78
1:36:43 PM	35.7622230	-120.9005728	0.62416854	-2.11011306	5.75959E-08	2.60054E-07	1.19618E-14	2.1874E-07	0.000866	4.57

1:36:44 PM	35.7622263	-120.9005580	0.62416860	-2.11011280	5.75959E-08	2.58309E-07	1.18128E-14	2.17374E-07	0.000861	4.54
1:36:45 PM	35.7622298	-120.9005423	0.62416866	-2.11011253	6.10865E-08	2.74017E-07	1.32928E-14	2.30589E-07	0.000913	4.82
1:36:46 PM	35.7622337	-120.9005270	0.62416873	-2.11011226	6.80678E-08	2.67035E-07	1.28965E-14	2.27125E-07	0.000899	4.75
1:36:47 PM	35.7622372	-120.9005120	0.62416879	-2.11011200	6.10865E-08	2.61799E-07	1.22153E-14	2.21045E-07	0.000875	4.62
1:36:48 PM	35.7622407	-120.9004967	0.62416885	-2.11011173	6.10865E-08	2.67035E-07	1.26711E-14	2.25132E-07	0.000891	4.71
1:36:49 PM	35.7622445	-120.9004813	0.62416891	-2.11011147	6.63225E-08	2.68781E-07	1.29918E-14	2.27963E-07	0.000903	4.77
1:36:50 PM	35.7622478	-120.9004658	0.62416897	-2.11011120	5.75959E-08	2.70526E-07	1.28764E-14	2.26948E-07	0.000898	4.74
1:36:51 PM	35.7622517	-120.9004503	0.62416904	-2.11011092	6.80678E-08	2.70526E-07	1.32054E-14	2.29829E-07	0.000910	4.80
1:36:52 PM	35.7622560	-120.9004357	0.62416912	-2.11011067	7.50492E-08	2.54818E-07	1.20967E-14	2.1997E-07	0.000871	4.60
1:36:53 PM	35.7622598	-120.9004205	0.62416918	-2.11011040	6.63225E-08	2.6529E-07	1.26849E-14	2.25254E-07	0.000892	4.71
1:36:54 PM	35.7622637	-120.9004053	0.62416925	-2.11011014	6.80678E-08	2.6529E-07	1.27435E-14	2.25774E-07	0.000894	4.72
1:36:55 PM	35.7622675	-120.9003903	0.62416932	-2.11010988	6.63225E-08	2.61799E-07	1.2382E-14	2.22549E-07	0.000881	4.65
1:36:56 PM	35.7622717	-120.9003760	0.62416939	-2.11010963	7.33038E-08	2.49582E-07	1.15973E-14	2.15381E-07	0.000853	4.50
1:36:57 PM	35.7622755	-120.9003605	0.62416946	-2.11010936	6.63225E-08	2.70526E-07	1.31467E-14	2.29318E-07	0.000908	4.79
1:36:58 PM	35.7622792	-120.9003450	0.62416952	-2.11010909	6.45772E-08	2.70526E-07	1.30896E-14	2.2882E-07	0.000906	4.78
1:36:59 PM	35.7622820	-120.9003300	0.62416957	-2.11010883	4.88692E-08	2.61799E-07	1.18794E-14	2.17985E-07	0.000863	4.56
1:37:00 PM	35.7622850	-120.9003153	0.62416962	-2.11010857	5.23599E-08	2.56563E-07	1.1521E-14	2.14671E-07	0.000850	4.49
1:37:01 PM	35.7622877	-120.9002988	0.62416967	-2.11010828	4.71239E-08	2.87979E-07	1.42068E-14	2.38385E-07	0.000944	4.98
1:37:02 PM	35.7622897	-120.9002818	0.62416970	-2.11010798	3.49066E-08	2.96706E-07	1.47962E-14	2.43279E-07	0.000963	5.09
1:37:03 PM	35.7622918	-120.9002660	0.62416974	-2.11010771	3.66519E-08	2.75762E-07	1.28537E-14	2.26749E-07	0.000898	4.74
1:37:04 PM	35.7622952	-120.9002510	0.62416980	-2.11010745	5.93412E-08	2.61799E-07	1.21627E-14	2.20569E-07	0.000873	4.61
1:37:05 PM	35.7622988	-120.9002360	0.62416986	-2.11010718	6.28319E-08	2.61799E-07	1.22693E-14	2.21534E-07	0.000877	4.63
1:37:06 PM	35.7623020	-120.9002207	0.62416992	-2.11010692	5.58505E-08	2.67035E-07	1.2518E-14	2.23767E-07	0.000886	4.68
1:37:07 PM	35.7623055	-120.9002058	0.62416998	-2.11010666	6.10865E-08	2.60054E-07	1.20653E-14	2.19684E-07	0.000870	4.59
1:37:08 PM	35.7623088	-120.9001905	0.62417004	-2.11010639	5.75959E-08	2.67035E-07	1.25675E-14	2.24209E-07	0.000888	4.69
1:37:09 PM	35.7623120	-120.9001747	0.62417009	-2.11010611	5.58505E-08	2.75762E-07	1.32977E-14	2.30631E-07	0.000913	4.82
1:37:10 PM	35.7623148	-120.9001590	0.62417014	-2.11010584	4.88692E-08	2.74017E-07	1.2957E-14	2.27657E-07	0.000901	4.76
1:37:11 PM	35.7623175	-120.9001433	0.62417019	-2.11010557	4.71239E-08	2.74017E-07	1.29151E-14	2.27289E-07	0.000900	4.75
1:37:12 PM	35.7623203	-120.9001273	0.62417024	-2.11010529	4.88692E-08	2.79253E-07	1.34338E-14	2.31809E-07	0.000918	4.85
1:37:13 PM	35.7623240	-120.9001120	0.62417030	-2.11010502	6.45772E-08	2.67035E-07	1.27807E-14	2.26103E-07	0.000895	4.73
1:37:14 PM	35.7623275	-120.9000963	0.62417036	-2.11010475	6.10865E-08	2.74017E-07	1.32928E-14	2.30589E-07	0.000913	4.82
1:37:15 PM	35.7623307	-120.9000805	0.62417042	-2.11010447	5.58505E-08	2.75762E-07	1.32977E-14	2.30631E-07	0.000913	4.82
1:37:16 PM	35.7623342	-120.9000655	0.62417048	-2.11010421	6.10865E-08	2.61799E-07	1.22152E-14	2.21045E-07	0.000875	4.62
1:37:17 PM	35.7623373	-120.9000507	0.62417053	-2.11010395	5.41052E-08	2.58309E-07	1.17153E-14	2.16475E-07	0.000857	4.53
1:37:18 PM	35.7623408	-120.9000358	0.62417060	-2.11010369	6.10865E-08	2.60054E-07	1.20653E-14	2.19684E-07	0.000870	4.59
1:37:19 PM	35.7623440	-120.9000203	0.62417065	-2.11010342	5.58505E-08	2.70526E-07	1.28268E-14	2.26511E-07	0.000897	4.73
1:37:20 PM	35.7623468	-120.9000050	0.62417070	-2.11010315	4.88692E-08	2.67035E-07	1.23352E-14	2.22128E-07	0.000879	4.64
1:37:21 PM	35.7623498	-120.8999897	0.62417075	-2.11010289	5.23599E-08	2.67035E-07	1.24235E-14	2.22922E-07	0.000883	4.66
1:37:22 PM	35.7623530	-120.8999743	0.62417081	-2.11010262	5.58505E-08	2.68781E-07	1.26719E-14	2.25139E-07	0.000891	4.71
1:37:23 PM	35.7623565	-120.8999590	0.62417087	-2.11010235	6.10865E-08	2.67035E-07	1.2671E-14	2.25131E-07	0.000891	4.71
1:37:24 PM	35.7623598	-120.8999438	0.62417093	-2.11010208	5.75959E-08	2.6529E-07	1.24145E-14	2.22841E-07	0.000882	4.66
1:37:25 PM	35.7623630	-120.8999283	0.62417098	-2.11010181	5.58505E-08	2.70526E-07	1.28268E-14	2.26511E-07	0.000897	4.73
1:37:26 PM	35.7623665	-120.8999132	0.62417104	-2.11010155	6.10865E-08	2.63545E-07	1.23661E-14	2.22406E-07	0.000881	4.65
1:37:27 PM	35.7623698	-120.8998975	0.62417110	-2.11010128	5.75959E-08	2.74017E-07	1.31892E-14	2.29689E-07	0.000909	4.80
1:37:28 PM	35.7623723	-120.8998818	0.62417114	-2.11010100	4.36332E-08	2.74017E-07	1.28359E-14	2.26591E-07	0.000897	4.74
1:37:29 PM	35.7623750	-120.8998662	0.62417119	-2.11010073	4.71239E-08	2.72271E-07	1.27581E-14	2.25904E-07	0.000894	4.72
1:37:30 PM	35.7623777	-120.8998500	0.62417124	-2.11010045	4.71239E-08	2.82743E-07	1.37149E-14	2.34221E-07	0.000927	4.90
1:37:31 PM	35.7623802	-120.8998343	0.62417128	-2.11010017	4.36332E-08	2.74017E-07	1.28359E-14	2.26591E-07	0.000897	4.74
1:37:32 PM	35.7623822	-120.8998188	0.62417132	-2.11009990	3.49066E-08	2.70526E-07	1.23516E-14	2.22276E-07	0.000880	4.65
1:37:33 PM	35.7623842	-120.8998032	0.62417135	-2.11009963	3.49066E-08	2.72271E-07	1.25076E-14	2.23675E-07	0.000886	4.68
1:37:34 PM	35.7623863	-120.8997870	0.62417139	-2.11009935	3.66519E-08	2.82743E-07	1.34955E-14	2.32341E-07	0.000920	4.86
1:37:35 PM	35.7623888	-120.8997710	0.62417143	-2.11009907	4.36332E-08	2.79253E-07	1.33127E-14	2.30762E-07	0.000914	4.82
1:37:36 PM	35.7623910	-120.8997557	0.62417147	-2.11009880	3.83972E-08	2.67035E-07	1.21067E-14	2.20061E-07	0.000871	4.60
1:37:37 PM	35.7623932	-120.8997397	0.62417151	-2.11009852	3.83972E-08	2.79253E-07	1.32054E-14	2.29829E-07	0.000910	4.80
1:37:38 PM	35.7623953	-120.8997238	0.62417155	-2.11009825	3.66519E-08	2.77507E-07	1.30126E-14	2.28146E-07	0.000903	4.77
1:37:39 PM	35.7623973	-120.8997092	0.62417158	-2.11009799	3.49066E-08	2.54818E-07	1.09932E-14	2.09697E-07	0.000830	4.38
1:37:40 PM	35.7623992	-120.8996933	0.62417161	-2.11009771	3.31613E-08	2.77507E-07	1.29517E-14	2.27611E-07	0.000901	4.76
1:37:41 PM	35.7624012	-120.8996768	0.62417165	-2.11009742	3.49066E-08	2.87979E-07	1.39562E-14	2.36273E-07	0.000935	4.94
1:37:42 PM	35.7624037	-120.8996618	0.62417169	-2.11009716	4.36332E-08	2.61799E-07	1.17583E-14	2.16871E-07	0.000859	4.53
1:37:43 PM	35.7624058	-120.8996467	0.62417173	-2.11009690	3.66519E-08	2.63545E-07	1.17691E-14	2.16971E-07	0.000859	4.54
1:37:44 PM	35.7624082	-120.8996307	0.62417177	-2.11009662	4.18879E-08	2.79253E-07	1.32754E-14	2.30438E-07	0.000912	4.82
1:37:45 PM	35.7624112	-120.8996155	0.62417182	-2.11009635	5.23599E-08	2.6529E-07	1.22706E-14	2.21545E-07	0.000877	4.63
1:37:46 PM	35.7624135	-120.8996003	0.62417186	-2.11009609	4.01426E-08	2.6529E-07	1.1988E-14	2.1898E-07	0.000867	4.58
1:37:47 PM	35.7624158	-120.8995847	0.62417190	-2.11009582	4.01426E-08	2.72271E-07	1.26058E-14	2.24551E-07	0.000889	4.69
1:37:48 PM	35.7624177	-120.8995685	0.62417194	-2.11009553	3.31613E-08	2.82743E-07	1.34346E-14	2.31815E-07	0.000918	4.85
1:37:49 PM	35.7624193	-120.8995528	0.62417197	-2.11009526	2.79253E-08	2.74017E-07	1.25548E-14	2.24097E-07	0.000887	4.68
1:37:50 PM	35.7624208	-120.8995367	0.62417199	-2.11009498	2.61799E-08	2.80998E-07	1.31691E-14	2.29513E-07	0.000909	4.80
1:37:51 PM	35.7624220	-120.8995205	0.62417201	-2.11009470	2.0944E-08	2.82743E-07	1.32693E-14	2.30385E-07	0.000912	4.82
1:37:52 PM	35.7624237	-120.8995037	0.62417204	-2.11009440	2.96706E-08	2.93215E-07	1.43726E-14	2.39772E-07	0.000949	5.01
1:37:53 PM	35.7624252	-120.8994878	0.62417207	-2.11009413	2.61799E-08	2.77507E-07	1.28481E-14	2.26699E-07	0.000898	4.74
1:37:54 PM	35.7624272	-120.8994713	0.62417210	-2.11009384	3.49066E-08	2.87979E-07	1.39562E-14	2.36273E-07	0.000935	4.94
1:37:55 PM	35.7624288	-120.8994557	0.62417213	-2.11009357	2.79253E-08	2.72271E-07	1.23979E-14	2.22692E-07	0.000882	4.66
1:37:56 PM	35.7624302	-120.8994392	0.62417216	-2.11009328	2.44346E-08	2.87979E-07	1.38009E-14	2.34954E-07	0.000930	4.91
1:37:57 PM	35.7624310	-120.8994230	0.62417217	-2.11009300	1.39626E-08	2.82743E-07	1.32084E-14	2.29856E-07	0.000910	4.80
1:37:58 PM	35.7624317	-120.8994073	0.62417218	-2.11009272	1.22173E-08	2.74017E-07	1.23972E-14	2.22685E-07	0.000882	4.65
1:37:59 PM	35.7624327	-120.8993912	0.62417220	-2.11009244	1.74533E-08	2.80998E-07	1.30739E-14	2.28682E-07	0.000905	4.78
1:38:00 PM	35.7624342	-120.8993753	0.62417223	-2.11009216	2.61799E-08	2.77507E-07	1.28481E-14	2.26699E-07	0.000898	4.74
1:38:01 PM	35.7624353	-120.8993592	0.62417224	-2.11009188	1.91986E-08	2.80998E-07	1.30899E-14	2.28822E-07	0.000906	4.78
1:38:02 PM	35.7624365	-120.8993433	0.62417227	-2.11009160	2.0944E-08	2.77507E-07	1.27865E-14	2.26154E-07	0.000895	4.73
1:38:03 PM	35.7624375	-120.8993262	0.62417228	-2.11009131	1.74533E-08	2.98451E-07	1.47386E-14	2.42806E-07	0.000961	5.08
1:38:04 PM	35.7624382	-120.8993100	0.62417230	-2.11009102	1.22173E-08	2.82743E-07	1.3197E-14	2.29756E-07	0.000910	4.80
1:38:05 PM	35.7624392	-120.8992943	0.62417231	-2.11009075	1.74533E-08	2.74017E-07	1.2436E-14	2.23034E-07	0.000883	4.66
1:38:06 PM	35.7624403	-120.8992782	0.62417233	-2.11009047	1.91986E-08	2.80998E-07	1.30899E-14	2.28822E-07	0.000906	4.78
1:38:07 PM	35.7624415	-120.8992620	0.62417235	-2.11009019	2.0944E-08	2.82743E-07	1.32693E-14	2.30385E-07	0.000912	4.82

1:38:08 PM	35.7624413	-120.8992458	0.62417235	-2.11008990	-3.49066E-09	2.82743E-07	1.31627E-14	2.29458E-07	0.000908	4.80
1:38:09 PM	35.7624413	-120.8992298	0.62417235	-2.11008962	0	2.79253E-07	1.28368E-14	2.26599E-07	0.000897	4.74
1:38:10 PM	35.7624415	-120.8992137	0.62417235	-2.11008934	3.49066E-09	2.80998E-07	1.30008E-14	2.28042E-07	0.000903	4.77
1:38:11 PM	35.7624420	-120.8991973	0.62417236	-2.11008906	8.72665E-09	2.86234E-07	1.35057E-14	2.32428E-07	0.000920	4.86
1:38:12 PM	35.7624418	-120.8991810	0.62417236	-2.11008877	-3.49066E-09	2.84489E-07	1.33257E-14	2.30874E-07	0.000914	4.83
1:38:13 PM	35.7624430	-120.8991648	0.62417238	-2.11008849	2.0944E-08	2.82743E-07	1.32693E-14	2.30385E-07	0.000912	4.82
1:38:14 PM	35.7624437	-120.8991487	0.62417239	-2.11008821	1.22173E-08	2.80998E-07	1.3035E-14	2.28342E-07	0.000904	4.77
1:38:15 PM	35.7624442	-120.8991327	0.62417240	-2.11008793	8.72665E-09	2.79253E-07	1.28558E-14	2.26767E-07	0.000898	4.74
1:38:16 PM	35.7624443	-120.8991168	0.62417240	-2.11008765	1.74533E-09	2.77507E-07	1.26776E-14	2.25189E-07	0.000892	4.71
1:38:17 PM	35.7624452	-120.8991008	0.62417242	-2.11008737	1.5708E-08	2.79253E-07	1.28984E-14	2.27143E-07	0.000899	4.75
1:38:18 PM	35.7624457	-120.8990847	0.62417243	-2.11008709	8.72665E-09	2.80998E-07	1.30167E-14	2.28182E-07	0.000903	4.77
1:38:19 PM	35.7624460	-120.8990683	0.62417243	-2.11008680	5.23599E-09	2.86234E-07	1.34935E-14	2.32323E-07	0.000920	4.86
1:38:20 PM	35.7624460	-120.8990523	0.62417243	-2.11008653	0	2.79253E-07	1.28367E-14	2.26599E-07	0.000897	4.74
1:38:21 PM	35.7624462	-120.8990365	0.62417243	-2.11008625	3.49066E-09	2.75762E-07	1.25209E-14	2.23794E-07	0.000886	4.68
1:38:22 PM	35.7624460	-120.8990205	0.62417243	-2.11008597	-3.49066E-09	2.79253E-07	1.28398E-14	2.26626E-07	0.000897	4.74
1:38:23 PM	35.7624462	-120.8990045	0.62417243	-2.11008569	3.49066E-09	2.79253E-07	1.28398E-14	2.26626E-07	0.000897	4.74
1:38:24 PM	35.7624462	-120.8989887	0.62417243	-2.11008542	0	2.75762E-07	1.25178E-14	2.23766E-07	0.000886	4.68
1:38:25 PM	35.7624455	-120.8989725	0.62417242	-2.11008513	-1.22173E-08	2.82743E-07	1.3197E-14	2.29756E-07	0.000910	4.80
1:38:26 PM	35.7624450	-120.8989560	0.62417241	-2.11008484	-8.72665E-09	2.87979E-07	1.36706E-14	2.33843E-07	0.000926	4.89
1:38:27 PM	35.7624445	-120.8989398	0.62417241	-2.11008456	-8.72665E-09	2.82743E-07	1.31787E-14	2.29597E-07	0.000909	4.80
1:38:28 PM	35.7624443	-120.8989248	0.62417240	-2.11008430	-3.49066E-09	2.61799E-07	1.12853E-14	2.12465E-07	0.000841	4.44
1:38:29 PM	35.7624437	-120.8989092	0.62417239	-2.11008403	-1.0472E-08	2.72271E-07	1.22304E-14	2.21182E-07	0.000876	4.62
1:38:30 PM	35.7624435	-120.8988935	0.62417239	-2.11008375	-3.49066E-09	2.74017E-07	1.23629E-14	2.22377E-07	0.000880	4.65
1:38:31 PM	35.7624428	-120.8988772	0.62417238	-2.11008347	-1.22173E-08	2.84489E-07	1.336E-14	2.31171E-07	0.000915	4.83
1:38:32 PM	35.7624423	-120.8988617	0.62417237	-2.11008320	-8.72665E-09	2.70526E-07	1.2066E-14	2.19691E-07	0.000870	4.59
1:38:33 PM	35.7624417	-120.8988463	0.62417236	-2.11008293	-1.0472E-08	2.68781E-07	1.19195E-14	2.18353E-07	0.000864	4.56
1:38:34 PM	35.7624410	-120.8988300	0.62417234	-2.11008265	-1.22173E-08	2.84489E-07	1.336E-14	2.31171E-07	0.000915	4.83
1:38:35 PM	35.7624403	-120.8988137	0.62417233	-2.11008236	-1.22173E-08	2.84489E-07	1.336E-14	2.31171E-07	0.000915	4.83
1:38:36 PM	35.7624393	-120.8987985	0.62417231	-2.11008210	-1.74533E-08	2.6529E-07	1.16613E-14	2.15975E-07	0.000855	4.51
1:38:37 PM	35.7624382	-120.8987823	0.62417230	-2.11008181	-1.91986E-08	2.82743E-07	1.32518E-14	2.30233E-07	0.000911	4.81
1:38:38 PM	35.7624375	-120.8987663	0.62417228	-2.11008153	-1.22173E-08	2.79253E-07	1.28741E-14	2.26928E-07	0.000898	4.74
1:38:39 PM	35.7624368	-120.8987510	0.62417227	-2.11008127	-1.22173E-08	2.67035E-07	1.17754E-14	2.17029E-07	0.000859	4.54
1:38:40 PM	35.7624360	-120.8987362	0.62417226	-2.11008101	-1.39626E-08	2.58309E-07	1.10322E-14	2.10068E-07	0.000832	4.39
1:38:41 PM	35.7624347	-120.8987193	0.62417223	-2.11008071	-2.26893E-08	2.94961E-07	1.44502E-14	2.40418E-07	0.000952	5.03
1:38:42 PM	35.7624347	-120.8987030	0.62417223	-2.11008043	0	2.84489E-07	1.33226E-14	2.30848E-07	0.000914	4.83
1:38:43 PM	35.7624335	-120.8986873	0.62417221	-2.11008015	-2.0944E-08	2.74017E-07	1.24696E-14	2.23334E-07	0.000884	4.67
1:38:44 PM	35.7624325	-120.8986723	0.62417220	-2.11007989	-1.74533E-08	2.61799E-07	1.13585E-14	2.13152E-07	0.000844	4.46
1:38:45 PM	35.7624320	-120.8986563	0.62417219	-2.11007961	-8.72665E-09	2.79253E-07	1.28558E-14	2.26767E-07	0.000898	4.74
1:38:46 PM	35.7624313	-120.8986412	0.62417217	-2.11007935	-1.22173E-08	2.63545E-07	1.14706E-14	2.14201E-07	0.000848	4.48
1:38:47 PM	35.7624303	-120.8986265	0.62417216	-2.11007909	-1.74533E-08	2.56563E-07	1.09117E-14	2.08918E-07	0.000827	4.37
1:38:48 PM	35.7624285	-120.8986115	0.62417213	-2.11007883	-3.14159E-08	2.61799E-07	1.1529E-14	2.14747E-07	0.000850	4.49
1:38:49 PM	35.7624272	-120.8985962	0.62417210	-2.11007856	-2.26893E-08	2.67035E-07	1.18668E-14	2.1787E-07	0.000863	4.55
1:38:50 PM	35.7624255	-120.8985812	0.62417207	-2.11007830	-2.96706E-08	2.61799E-07	1.15024E-14	2.14498E-07	0.000849	4.48
1:38:51 PM	35.7624245	-120.8985672	0.62417206	-2.11007806	-1.74533E-08	2.44346E-07	9.9043E-15	1.99041E-07	0.000788	4.16
1:38:52 PM	35.7624228	-120.8985525	0.62417203	-2.11007780	-2.96706E-08	2.56563E-07	1.10556E-14	2.10291E-07	0.000833	4.40
1:38:53 PM	35.7624207	-120.8985370	0.62417199	-2.11007753	-3.66519E-08	2.70526E-07	1.23828E-14	2.22556E-07	0.000881	4.65
1:38:54 PM	35.7624185	-120.8985220	0.62417195	-2.11007727	-3.83972E-08	2.61799E-07	1.16509E-14	2.15879E-07	0.000855	4.51
1:38:55 PM	35.7624157	-120.8985077	0.62417190	-2.11007702	-4.88692E-08	2.49582E-07	1.08509E-14	2.08335E-07	0.000825	4.35
1:38:56 PM	35.7624125	-120.8984923	0.62417185	-2.11007675	-5.58505E-08	2.68781E-07	1.26719E-14	2.25139E-07	0.000891	4.71
1:38:57 PM	35.7624093	-120.8984768	0.62417179	-2.11007648	-5.58505E-08	2.70526E-07	1.28268E-14	2.26511E-07	0.000897	4.73
1:38:58 PM	35.7624063	-120.8984620	0.62417174	-2.11007622	-5.23599E-08	2.58309E-07	1.16688E-14	2.16045E-07	0.000855	4.52
1:38:59 PM	35.7624028	-120.8984472	0.62417168	-2.11007596	-6.10865E-08	2.58309E-07	1.19163E-14	2.18324E-07	0.000864	4.56
1:39:00 PM	35.7623992	-120.8984315	0.62417161	-2.11007569	-6.28319E-08	2.74017E-07	1.33469E-14	2.31057E-07	0.000915	4.83
1:39:01 PM	35.7623958	-120.8984162	0.62417156	-2.11007542	-5.93412E-08	2.67035E-07	1.26185E-14	2.24664E-07	0.000889	4.70
1:39:02 PM	35.7623923	-120.8984012	0.62417149	-2.11007516	-6.10865E-08	2.61799E-07	1.22152E-14	2.21045E-07	0.000875	4.62
1:39:03 PM	35.7623888	-120.8983860	0.62417143	-2.11007490	-6.10865E-08	2.6529E-07	1.25181E-14	2.23768E-07	0.000886	4.68
1:39:04 PM	35.7623850	-120.8983705	0.62417137	-2.11007463	-6.63225E-08	2.70526E-07	1.31467E-14	2.29318E-07	0.000908	4.79
1:39:05 PM	35.7623805	-120.8983553	0.62417129	-2.11007436	-7.85398E-08	2.6529E-07	1.31273E-14	2.29149E-07	0.000907	4.79
1:39:06 PM	35.7623762	-120.8983412	0.62417121	-2.11007411	-7.50492E-08	2.46091E-07	1.13772E-14	2.13327E-07	0.000845	4.46
1:39:07 PM	35.7623712	-120.8983270	0.62417113	-2.11007387	-8.72665E-08	2.47837E-07	1.20148E-14	2.19224E-07	0.000868	4.58
1:39:08 PM	35.7623658	-120.8983128	0.62417103	-2.11007362	-9.42478E-08	2.47837E-07	1.23316E-14	2.22096E-07	0.000879	4.64
1:39:09 PM	35.7623602	-120.8982997	0.62417093	-2.11007339	-9.77384E-08	2.28638E-07	1.09934E-14	2.09698E-07	0.000830	4.38
1:39:10 PM	35.7623535	-120.8982870	0.62417082	-2.11007317	-1.16937E-07	2.21657E-07	1.15062E-14	2.14534E-07	0.000849	4.48
1:39:11 PM	35.7623465	-120.8982760	0.62417069	-2.11007298	-1.22173E-07	1.91986E-07	9.79895E-15	1.97979E-07	0.000784	4.14
1:39:12 PM	35.7623385	-120.8982665	0.62417056	-2.11007281	-1.39626E-07	1.65806E-07	9.39935E-15	1.939E-07	0.000768	4.05
1:39:13 PM	35.7623305	-120.8982603	0.62417042	-2.11007270	-1.39626E-07	1.0821E-07	6.8014E-15	1.64941E-07	0.000653	3.45
1:39:14 PM	35.7623237	-120.8982582	0.62417030	-2.11007267	-1.18682E-07	3.66519E-08	3.74251E-15	1.22352E-07	0.000484	2.56
1:39:15 PM	35.7623198	-120.8982603	0.62417023	-2.11007270	-6.80678E-08	-3.66519E-08	1.37944E-15	7.42817E-08	0.000294	1.55
1:39:16 PM	35.7623185	-120.8982608	0.62417021	-2.11007271	-2.26893E-08	-8.72665E-09	1.41237E-16	2.37686E-08	0.000094	0.50
Run 2										
1:45:46 PM	35.7624142	-120.8987313	0.62417188	-2.11008092	--	--	--	--	--	--
1:45:47 PM	35.7624145	-120.8987328	0.62417188	-2.11008095	5.23599E-09	-2.61799E-08	1.19677E-16	2.18794E-08	0.000087	0.46
1:45:48 PM	35.7624192	-120.8987337	0.62417196	-2.11008096	8.20305E-08	-1.5708E-08	1.72287E-15	8.30148E-08	0.000329	1.74
1:45:49 PM	35.7624275	-120.8987378	0.62417211	-2.11008104	1.44862E-07	-7.15585E-08	6.08919E-15	1.56066E-07	0.000618	3.26
1:45:50 PM	35.7624365	-120.8987462	0.62417227	-2.11008118	1.5708E-07	-1.46608E-07	9.70663E-15	1.97044E-07	0.000780	4.12
1:45:51 PM	35.7624438	-120.8987588	0.62417239	-2.11008140	1.27409E-07	-2.19911E-07	1.20191E-14	2.19263E-07	0.000868	4.58
1:45:52 PM	35.7624483	-120.8987743	0.62417247	-2.11008167	7.85398E-08	-2.70526E-07	1.35891E-14	2.33145E-07	0.000923	4.87
1:45:53 PM	35.7624500	-120.8987905	0.62417250	-2.11008196	2.96706E-08	-2.82743E-07	1.33798E-14	2.31342E-07	0.000916	4.84
1:45:54 PM	35.7624493	-120.8988070	0.62417249	-2.11008224	-1.22173E-08	-2.87979E-07	1.36889E-14	2.33999E-07	0.000926	4.89
1:45:55 PM	35.7624472	-120.8988237	0.62417245	-2.11008254	-3.66519E-08	-2.9147E-07	1.43204E-14	2.39336E-07	0.000948	5.00
1:45:56 PM	35.7624435	-120.8988398	0.62417239	-2.11008282	-6.45772E-08	-2.80998E-07	1.40403E-14	2.36983E-07	0.000938	4.95
1:45:57 PM	35.7624373	-120.8988547	0.62417228	-2.11008308	-1.0821E-07	-2.60054E-07	1.40597E-14	2.37148E-07	0.000939	4.96
1:45:58 PM	35.7624315	-120.8988705	0.62417218	-2.11008335	-1.01229E-07	-2.75762E-07	1.50797E-14	2.45599E-07	0.000972	5.13
1:45:59 PM	35.7624257	-120.8988860	0.62417208	-2.11008362	-1.01229E-07	-2.70526E-07	1.46088E-14	2.41734E-07	0.000957	5.05

1:46:00 PM	35.7624192	-120.8989008	0.62417196	-2.11008388	-1.13446E-07	-2.58309E-07	1.4201E-14	2.38336E-07	0.000944	4.98
1:46:01 PM	35.7624120	-120.8989158	0.62417184	-2.11008414	-1.25664E-07	-2.61799E-07	1.52302E-14	2.46821E-07	0.000977	5.16
1:46:02 PM	35.7624043	-120.8989310	0.62417170	-2.11008441	-1.3439E-07	-2.6529E-07	1.61004E-14	2.53774E-07	0.001005	5.30
1:46:03 PM	35.7623965	-120.8989452	0.62417157	-2.11008466	-1.36136E-07	-2.47837E-07	1.47442E-14	2.42851E-07	0.000961	5.08
1:46:04 PM	35.7623885	-120.8989595	0.62417143	-2.11008491	-1.39626E-07	-2.49582E-07	1.51277E-14	2.4599E-07	0.000974	5.14
1:46:05 PM	35.7623805	-120.8989733	0.62417129	-2.11008515	-1.39626E-07	-2.40855E-07	1.44232E-14	2.40194E-07	0.000951	5.02
1:46:06 PM	35.7623725	-120.8989867	0.62417115	-2.11008538	-1.39626E-07	-2.33874E-07	1.38777E-14	2.35607E-07	0.000933	4.93
1:46:07 PM	35.7623643	-120.8990000	0.62417101	-2.11008561	-1.43117E-07	-2.32129E-07	1.39905E-14	2.36563E-07	0.000937	4.95
1:46:08 PM	35.7623558	-120.8990135	0.62417086	-2.11008585	-1.48353E-07	-2.35619E-07	1.46408E-14	2.41999E-07	0.000958	5.06
1:46:09 PM	35.7623475	-120.8990272	0.62417071	-2.11008609	-1.44862E-07	-2.3911E-07	1.46577E-14	2.42138E-07	0.000959	5.06
1:46:10 PM	35.7623392	-120.8990403	0.62417057	-2.11008632	-1.44862E-07	-2.28638E-07	1.38514E-14	2.35384E-07	0.000932	4.92
1:46:11 PM	35.7623310	-120.8990537	0.62417042	-2.11008655	-1.43117E-07	-2.33874E-07	1.41244E-14	2.37692E-07	0.000941	4.97
1:46:12 PM	35.7623228	-120.8990675	0.62417028	-2.11008679	-1.43117E-07	-2.40855E-07	1.467E-14	2.42239E-07	0.000959	5.06
1:46:13 PM	35.7623148	-120.8990807	0.62417014	-2.11008702	-1.39626E-07	-2.30383E-07	1.36109E-14	2.33332E-07	0.000924	4.88
1:46:14 PM	35.7623068	-120.8990942	0.62417000	-2.11008726	-1.39626E-07	-2.35619E-07	1.40126E-14	2.36749E-07	0.000937	4.95
1:46:15 PM	35.7622988	-120.8991083	0.62416986	-2.11008750	-1.39626E-07	-2.46091E-07	1.4843E-14	2.43663E-07	0.000965	5.09
1:46:16 PM	35.7622907	-120.8991220	0.62416972	-2.11008774	-1.41372E-07	-2.3911E-07	1.4408E-14	2.40066E-07	0.000950	5.02
1:46:17 PM	35.7622825	-120.8991355	0.62416958	-2.11008798	-1.43117E-07	-2.35619E-07	1.42593E-14	2.38825E-07	0.000946	4.99
1:46:18 PM	35.7622742	-120.8991490	0.62416943	-2.11008821	-1.44862E-07	-2.35619E-07	1.4385E-14	2.39875E-07	0.000950	5.01
1:46:19 PM	35.7622662	-120.8991620	0.62416929	-2.11008844	-1.39626E-07	-2.26893E-07	1.33482E-14	2.31069E-07	0.000915	4.83
1:46:20 PM	35.7622580	-120.8991753	0.62416915	-2.11008867	-1.43117E-07	-2.32129E-07	1.39906E-14	2.36563E-07	0.000937	4.95
1:46:21 PM	35.7622498	-120.8991890	0.62416901	-2.11008891	-1.43117E-07	-2.3911E-07	1.45321E-14	2.41098E-07	0.000955	5.04
1:46:22 PM	35.7622420	-120.8992023	0.62416887	-2.11008914	-1.36136E-07	-2.32129E-07	1.35032E-14	2.32406E-07	0.000920	4.86
1:46:23 PM	35.7622342	-120.8992157	0.62416873	-2.11008938	-1.36136E-07	-2.33874E-07	1.36371E-14	2.33556E-07	0.000925	4.88
1:46:24 PM	35.7622260	-120.8992288	0.62416859	-2.11008961	-1.43117E-07	-2.28638E-07	1.37258E-14	2.34314E-07	0.000928	4.90
1:46:25 PM	35.7622178	-120.8992423	0.62416845	-2.11008984	-1.43117E-07	-2.35619E-07	1.42593E-14	2.38825E-07	0.000946	4.99
1:46:26 PM	35.7622100	-120.8992562	0.62416831	-2.11009008	-1.36136E-07	-2.42601E-07	1.43215E-14	2.39345E-07	0.000948	5.00
1:46:27 PM	35.7622020	-120.8992700	0.62416817	-2.11009032	-1.39626E-07	-2.40855E-07	1.44233E-14	2.40194E-07	0.000951	5.02
1:46:28 PM	35.7621942	-120.8992837	0.62416804	-2.11009056	-1.36136E-07	-2.3911E-07	1.40447E-14	2.37021E-07	0.000938	4.95
1:46:29 PM	35.7621863	-120.8992970	0.62416790	-2.11009080	-1.37881E-07	-2.32129E-07	1.36227E-14	2.33433E-07	0.000924	4.88
1:46:30 PM	35.7621785	-120.8993108	0.62416776	-2.11009104	-1.36136E-07	-2.40855E-07	1.41826E-14	2.38182E-07	0.000943	4.98
1:46:31 PM	35.7621705	-120.8993245	0.62416762	-2.11009128	-1.39626E-07	-2.3911E-07	1.42854E-14	2.39043E-07	0.000946	5.00
1:46:32 PM	35.7621627	-120.8993380	0.62416749	-2.11009151	-1.36136E-07	-2.35619E-07	1.3772E-14	2.34708E-07	0.000929	4.91
1:46:33 PM	35.7621550	-120.8993517	0.62416735	-2.11009175	-1.3439E-07	-2.3911E-07	1.39267E-14	2.36023E-07	0.000934	4.93
1:46:34 PM	35.7621470	-120.8993653	0.62416721	-2.11009199	-1.39626E-07	-2.37365E-07	1.41485E-14	2.37895E-07	0.000942	4.97
1:46:35 PM	35.7621388	-120.8993788	0.62416707	-2.11009222	-1.43117E-07	-2.35619E-07	1.42594E-14	2.38825E-07	0.000946	4.99
1:46:36 PM	35.7621312	-120.8993925	0.62416694	-2.11009246	-1.32645E-07	-2.3911E-07	1.38102E-14	2.35034E-07	0.000930	4.91
1:46:37 PM	35.7621235	-120.8994060	0.62416680	-2.11009270	-1.3439E-07	-2.35619E-07	1.36539E-14	2.337E-07	0.000925	4.89
1:46:38 PM	35.7621157	-120.8994200	0.62416667	-2.11009294	-1.36136E-07	-2.44346E-07	1.44614E-14	2.40512E-07	0.000952	5.03
1:46:39 PM	35.7621082	-120.8994342	0.62416654	-2.11009319	-1.309E-07	-2.47837E-07	1.43947E-14	2.39956E-07	0.000950	5.02
1:46:40 PM	35.7621008	-120.8994477	0.62416641	-2.11009343	-1.29154E-07	-2.35619E-07	1.3309E-14	2.30729E-07	0.000913	4.82
1:46:41 PM	35.7620933	-120.8994618	0.62416628	-2.11009367	-1.309E-07	-2.46091E-07	1.42528E-14	2.3877E-07	0.000945	4.99
1:46:42 PM	35.7620860	-120.8994758	0.62416615	-2.11009392	-1.27409E-07	-2.44346E-07	1.38865E-14	2.35682E-07	0.000933	4.93
1:46:43 PM	35.7620785	-120.8994898	0.62416602	-2.11009416	-1.309E-07	-2.44346E-07	1.41119E-14	2.37587E-07	0.000941	4.97
1:46:44 PM	35.7620712	-120.8995038	0.62416589	-2.11009441	-1.27409E-07	-2.44346E-07	1.38865E-14	2.35682E-07	0.000933	4.93
1:46:45 PM	35.7620637	-120.8995180	0.62416576	-2.11009465	-1.309E-07	-2.47837E-07	1.43947E-14	2.39956E-07	0.000950	5.02
1:46:46 PM	35.7620563	-120.8995322	0.62416563	-2.11009490	-1.29154E-07	-2.47837E-07	1.42813E-14	2.39008E-07	0.000946	5.00
1:46:47 PM	35.7620488	-120.8995465	0.62416550	-2.11009515	-1.309E-07	-2.49582E-07	1.45376E-14	2.41144E-07	0.000955	5.04
1:46:48 PM	35.7620415	-120.8995608	0.62416537	-2.11009540	-1.27409E-07	-2.49582E-07	1.43122E-14	2.39267E-07	0.000947	5.00
1:46:49 PM	35.7620342	-120.8995752	0.62416524	-2.11009565	-1.27409E-07	-2.51327E-07	1.44561E-14	2.40467E-07	0.000952	5.03
1:46:50 PM	35.7620268	-120.8995893	0.62416511	-2.11009590	-1.29154E-07	-2.46091E-07	1.41394E-14	2.37818E-07	0.000942	4.97
1:46:51 PM	35.7620193	-120.8996037	0.62416498	-2.11009615	-1.309E-07	-2.51327E-07	1.46816E-14	2.42335E-07	0.000959	5.07
1:46:52 PM	35.7620118	-120.8996182	0.62416485	-2.11009640	-1.309E-07	-2.53073E-07	1.48265E-14	2.43528E-07	0.000964	5.09
1:46:53 PM	35.7620043	-120.8996323	0.62416472	-2.11009665	-1.309E-07	-2.46091E-07	1.42528E-14	2.3877E-07	0.000945	4.99
1:46:54 PM	35.7619968	-120.8996463	0.62416459	-2.11009689	-1.309E-07	-2.44346E-07	1.41119E-14	2.37587E-07	0.000941	4.97
1:46:55 PM	35.7619893	-120.8996607	0.62416446	-2.11009714	-1.309E-07	-2.51327E-07	1.46816E-14	2.42335E-07	0.000959	5.07
1:46:56 PM	35.7619820	-120.8996748	0.62416433	-2.11009739	-1.27409E-07	-2.46091E-07	1.40274E-14	2.36875E-07	0.000938	4.95
1:46:57 PM	35.7619747	-120.8996892	0.62416421	-2.11009764	-1.27409E-07	-2.51327E-07	1.44562E-14	2.40468E-07	0.000952	5.03
1:46:58 PM	35.7619678	-120.8997037	0.62416409	-2.11009789	-1.20428E-07	-2.53073E-07	1.41685E-14	2.38063E-07	0.000942	4.98
1:46:59 PM	35.7619610	-120.8997178	0.62416397	-2.11009814	-1.18682E-07	-2.46091E-07	1.34905E-14	2.32298E-07	0.000920	4.86
1:47:00 PM	35.7619538	-120.8997322	0.62416384	-2.11009839	-1.25664E-07	-2.51327E-07	1.43457E-14	2.39547E-07	0.000948	5.01
1:47:01 PM	35.7619470	-120.8997467	0.62416372	-2.11009864	-1.18682E-07	-2.53073E-07	1.40642E-14	2.37185E-07	0.000939	4.96
1:47:02 PM	35.7619403	-120.8997608	0.62416361	-2.11009889	-1.16937E-07	-2.46091E-07	1.33877E-14	2.31411E-07	0.000916	4.84
1:47:03 PM	35.7619337	-120.8997752	0.62416349	-2.11009914	-1.15192E-07	-2.51327E-07	1.37152E-14	2.34224E-07	0.000927	4.90
1:47:04 PM	35.7619265	-120.8997898	0.62416336	-2.11009940	-1.25664E-07	-2.54818E-07	1.46366E-14	2.41963E-07	0.000958	5.06
1:47:05 PM	35.7619200	-120.8998043	0.62416325	-2.11009965	-1.13446E-07	-2.53073E-07	1.37603E-14	2.34609E-07	0.000929	4.90
1:47:06 PM	35.7619133	-120.8998187	0.62416313	-2.11009990	-1.16937E-07	-2.51327E-07	1.38165E-14	2.35087E-07	0.000931	4.91
1:47:07 PM	35.7619067	-120.8998323	0.62416302	-2.11010014	-1.15192E-07	-2.37365E-07	1.2592E-14	2.24428E-07	0.000889	4.69
1:47:08 PM	35.7619003	-120.8998463	0.62416291	-2.11010038	-1.11701E-07	-2.44346E-07	1.29476E-14	2.27575E-07	0.000901	4.76
1:47:09 PM	35.7618935	-120.8998608	0.62416279	-2.11010064	-1.18682E-07	-2.53073E-07	1.40642E-14	2.37185E-07	0.000939	4.96
1:47:10 PM	35.7618878	-120.8998730	0.62416269	-2.11010085	-9.94838E-08	-2.1293E-07	9.93773E-15	1.99376E-07	0.000789	4.17
1:47:11 PM	35.7618822	-120.8998843	0.62416259	-2.11010105	-9.77384E-08	-1.97222E-07	8.79112E-15	1.87522E-07	0.000742	3.92
1:47:12 PM	35.7618757	-120.8998973	0.62416248	-2.11010127	-1.13446E-07	-2.26893E-07	1.16919E-14	2.16258E-07	0.000856	4.52
1:47:13 PM	35.7618688	-120.8999115	0.62416236	-2.11010152	-1.20428E-07	-2.47837E-07	1.37368E-14	2.34408E-07	0.000928	4.90
1:47:14 PM	35.7618623	-120.8999270	0.62416224	-2.11010179	-1.13446E-07	-2.70526E-07	1.52647E-14	2.47101E-07	0.000978	5.17
1:47:15 PM	35.7618552	-120.8999412	0.62416212	-2.11010204	-1.23918E-07	-2.47837E-07	1.395E-14	2.36221E-07	0.000935	4.94
1:47:16 PM	35.7618490	-120.8999562	0.62416201	-2.11010230	-1.0821E-07	-2.61799E-07	1.42098E-14	2.3841E-07	0.000944	4.98
1:47:17 PM	35.7618420	-120.8999713	0.62416189	-2.11010256	-1.22173E-07	-2.63545E-07	1.5165E-14	2.46292E-07	0.000975	5.15
1:47:18 PM	35.7618355	-120.8999862	0.62416178	-2.11010282	-1.13446E-07	-2.60054E-07	1.43501E-14	2.39583E-07	0.000949	5.01
1:47:19 PM	35.7618290	-120.9000010	0.62416166	-2.11010308	-1.13446E-07	-2.58309E-07	1.42011E-14	2.38337E-07	0.000944	4.98
1:47:20 PM	35.7618230	-120.9000163	0.62416156	-2.11010335	-1.0472E-07	-2.67035E-07	1.44798E-14	2.40664E-07	0.000953	5.03
1:47:21 PM	35.7618170	-120.9000315	0.62416145	-2.11010362	-1.0472E-07	-2.6529E-07	1.43269E-14	2.3939E-07	0.000948	5.00
1:47:22 PM	35.7618108	-120.9000465	0.62416134	-2.11010388	-1.0821E-07	-2.61799E-07	1.42099E-14	2.3841E-07	0.000944	4.98
1:47:23 PM	35.7618045	-120.9000617	0.62416123	-2.11010414	-1.09956E-07	-2.6529E-07	1.46079E-14	2.41726E-07	0.000957	5.05

1:47:24 PM	35.7617982	-120.9000770	0.62416113	-2.11010441	-1.09956E-07	-2.67035E-07	1.47609E-14	2.42989E-07	0.000962	5.08
1:47:25 PM	35.7617920	-120.9000922	0.62416102	-2.11010467	-1.0821E-07	-2.6529E-07	1.45127E-14	2.40938E-07	0.000954	5.04
1:47:26 PM	35.7617857	-120.9001070	0.62416091	-2.11010493	-1.09956E-07	-2.58309E-07	1.40062E-14	2.36696E-07	0.000937	4.95
1:47:27 PM	35.7617798	-120.9001223	0.62416080	-2.11010520	-1.02974E-07	-2.67035E-07	1.43892E-14	2.3991E-07	0.000950	5.01
1:47:28 PM	35.7617742	-120.9001377	0.62416071	-2.11010547	-9.77384E-08	-2.68781E-07	1.42804E-14	2.39002E-07	0.000946	5.00
1:47:29 PM	35.7617678	-120.9001528	0.62416059	-2.11010573	-1.11701E-07	-2.63545E-07	1.45527E-14	2.41269E-07	0.000955	5.04
1:47:30 PM	35.7617613	-120.9001680	0.62416048	-2.11010600	-1.13446E-07	-2.6529E-07	1.48029E-14	2.43334E-07	0.000963	5.09
1:47:31 PM	35.7617555	-120.9001837	0.62416038	-2.11010627	-1.01229E-07	-2.74017E-07	1.49219E-14	2.44311E-07	0.000967	5.11
1:47:32 PM	35.7617498	-120.9001988	0.62416028	-2.11010654	-9.94838E-08	-2.63545E-07	1.39077E-14	2.35862E-07	0.000934	4.93
1:47:33 PM	35.7617443	-120.9002135	0.62416018	-2.11010679	-9.59931E-08	-2.56563E-07	1.31394E-14	2.29254E-07	0.000908	4.79
1:47:34 PM	35.7617390	-120.9002285	0.62416009	-2.11010705	-9.25025E-08	-2.61799E-07	1.34217E-14	2.31704E-07	0.000917	4.84
1:47:35 PM	35.7617333	-120.9002435	0.62415999	-2.11010732	-9.94838E-08	-2.61799E-07	1.37568E-14	2.34578E-07	0.000929	4.90
1:47:36 PM	35.7617277	-120.9002585	0.62415989	-2.11010758	-9.77384E-08	-2.61799E-07	1.36707E-14	2.33844E-07	0.000926	4.89
1:47:37 PM	35.7617218	-120.9002737	0.62415979	-2.11010784	-1.02974E-07	-2.6529E-07	1.42363E-14	2.38632E-07	0.000945	4.99
1:47:38 PM	35.7617167	-120.9002893	0.62415970	-2.11010811	-8.90118E-08	-2.72271E-07	1.41839E-14	2.38193E-07	0.000943	4.98
1:47:39 PM	35.7617122	-120.9003060	0.62415962	-2.11010841	-7.85398E-08	-2.9147E-07	1.55269E-14	2.49214E-07	0.000987	5.21
1:47:40 PM	35.7617087	-120.9003230	0.62415956	-2.11010870	-6.10865E-08	-2.96706E-07	1.54246E-14	2.48392E-07	0.000983	5.19
1:47:41 PM	35.7617050	-120.9003398	0.62415950	-2.11010900	-6.45772E-08	-2.93215E-07	1.51953E-14	2.46539E-07	0.000976	5.15
1:47:42 PM	35.7617012	-120.9003568	0.62415943	-2.11010929	-6.63225E-08	-2.96706E-07	1.55914E-14	2.49731E-07	0.000989	5.22
1:47:43 PM	35.7616973	-120.9003735	0.62415936	-2.11010958	-6.80678E-08	-2.9147E-07	1.51431E-14	2.46115E-07	0.000974	5.14
1:47:44 PM	35.7616932	-120.9003903	0.62415929	-2.11010988	-7.15585E-08	-2.93215E-07	1.54329E-14	2.48459E-07	0.000984	5.19
1:47:45 PM	35.7616893	-120.9004070	0.62415922	-2.11011017	-6.80678E-08	-2.9147E-07	1.51431E-14	2.46115E-07	0.000974	5.14
1:47:46 PM	35.7616852	-120.9004242	0.62415915	-2.11011047	-7.15585E-08	-3.00197E-07	1.61149E-14	2.53889E-07	0.001005	5.31
1:47:47 PM	35.7616803	-120.9004410	0.62415907	-2.11011076	-8.55211E-08	-2.93215E-07	1.59813E-14	2.52834E-07	0.001001	5.29
1:47:48 PM	35.7616758	-120.9004577	0.62415899	-2.11011105	-7.85398E-08	-2.9147E-07	1.55269E-14	2.49214E-07	0.000987	5.21
1:47:49 PM	35.7616712	-120.9004745	0.62415891	-2.11011135	-8.02851E-08	-2.93215E-07	1.57642E-14	2.51111E-07	0.000994	5.25
1:47:50 PM	35.7616660	-120.9004910	0.62415882	-2.11011164	-9.07571E-08	-2.87979E-07	1.57111E-14	2.50688E-07	0.000992	5.24
1:47:51 PM	35.7616607	-120.9005067	0.62415873	-2.11011191	-9.25025E-08	-2.74017E-07	1.44993E-14	2.40826E-07	0.000953	5.03
1:47:52 PM	35.7616550	-120.9005223	0.62415863	-2.11011218	-9.94838E-08	-2.72271E-07	1.46774E-14	2.42301E-07	0.000959	5.06
1:47:53 PM	35.7616498	-120.9005383	0.62415853	-2.11011246	-9.07571E-08	-2.79253E-07	1.48962E-14	2.441E-07	0.000966	5.10
1:47:54 PM	35.7616447	-120.9005542	0.62415845	-2.11011274	-8.90118E-08	-2.77507E-07	1.46578E-14	2.42139E-07	0.000959	5.06
1:47:55 PM	35.7616400	-120.9005702	0.62415836	-2.11011302	-8.20305E-08	-2.79253E-07	1.45193E-14	2.40992E-07	0.000954	5.04
1:47:56 PM	35.7616353	-120.9005865	0.62415828	-2.11011330	-8.20305E-08	-2.84489E-07	1.50052E-14	2.44991E-07	0.000970	5.12
1:47:57 PM	35.7616305	-120.9006035	0.62415820	-2.11011360	-8.37758E-08	-2.96706E-07	1.62464E-14	2.54923E-07	0.001009	5.33
1:47:58 PM	35.7616262	-120.9006198	0.62415812	-2.11011388	-7.50492E-08	-2.84489E-07	1.4731E-14	2.42743E-07	0.000961	5.07
1:47:59 PM	35.7616223	-120.9006360	0.62415805	-2.11011417	-6.80678E-08	-2.82743E-07	1.43183E-14	2.39318E-07	0.000947	5.00
1:48:00 PM	35.7616188	-120.9006527	0.62415799	-2.11011446	-6.10865E-08	-2.9147E-07	1.49177E-14	2.44276E-07	0.000967	5.11
1:48:01 PM	35.7616148	-120.9006697	0.62415792	-2.11011475	-6.98132E-08	-2.96706E-07	1.57103E-14	2.50681E-07	0.000992	5.24
1:48:02 PM	35.7616118	-120.9006857	0.62415787	-2.11011503	-5.23599E-08	-2.79253E-07	1.35224E-14	2.32572E-07	0.000921	4.86
1:48:03 PM	35.7616085	-120.9007023	0.62415781	-2.11011532	-5.75959E-08	-2.89725E-07	1.46472E-14	2.42051E-07	0.000958	5.06
1:48:04 PM	35.7616053	-120.9007190	0.62415776	-2.11011561	-5.58505E-08	-2.9147E-07	1.47647E-14	2.4302E-07	0.000962	5.08
1:48:05 PM	35.7616020	-120.9007355	0.62415770	-2.11011590	-5.75959E-08	-2.87979E-07	1.44812E-14	2.40676E-07	0.000953	5.03
1:48:06 PM	35.7615988	-120.9007520	0.62415764	-2.11011619	-5.58505E-08	-2.87979E-07	1.44317E-14	2.40264E-07	0.000951	5.02
1:48:07 PM	35.7615957	-120.9007690	0.62415759	-2.11011649	-5.41052E-08	-2.96706E-07	1.52236E-14	2.46768E-07	0.000977	5.16
1:48:08 PM	35.7615928	-120.9007857	0.62415754	-2.11011678	-5.06145E-08	-2.9147E-07	1.46253E-14	2.4187E-07	0.000958	5.06
1:48:09 PM	35.7615900	-120.9008017	0.62415749	-2.11011706	-4.88692E-08	-2.79253E-07	1.34341E-14	2.31811E-07	0.000918	4.85
1:48:10 PM	35.7615873	-120.9008180	0.62415744	-2.11011734	-4.71239E-08	-2.84489E-07	1.38781E-14	2.35611E-07	0.000933	4.93
1:48:11 PM	35.7615847	-120.9008347	0.62415740	-2.11011763	-4.53786E-08	-2.9147E-07	1.44996E-14	2.40829E-07	0.000953	5.03
1:48:12 PM	35.7615823	-120.9008513	0.62415736	-2.11011792	-4.18879E-08	-2.89725E-07	1.42565E-14	2.38801E-07	0.000945	4.99
1:48:13 PM	35.7615805	-120.9008678	0.62415733	-2.11011821	-3.14159E-08	-2.87979E-07	1.38986E-14	2.35785E-07	0.000933	4.93
1:48:14 PM	35.7615778	-120.9008845	0.62415728	-2.11011850	-4.71239E-08	-2.9147E-07	1.454E-14	2.41164E-07	0.000955	5.04
1:48:15 PM	35.7615765	-120.9009015	0.62415726	-2.11011880	-2.26893E-08	-2.96706E-07	1.46205E-14	2.41831E-07	0.000957	5.06
1:48:16 PM	35.7615742	-120.9009180	0.62415722	-2.11011909	-4.01426E-08	-2.87979E-07	1.40547E-14	2.37105E-07	0.000939	4.96
1:48:17 PM	35.7615727	-120.9009343	0.62415719	-2.11011937	-2.61799E-08	-2.84489E-07	1.34943E-14	2.3233E-07	0.000920	4.86
1:48:18 PM	35.7615707	-120.9009513	0.62415715	-2.11011967	-3.49066E-08	-2.96706E-07	1.47964E-14	2.43281E-07	0.000963	5.09
1:48:19 PM	35.7615695	-120.9009677	0.62415713	-2.11011996	-2.0944E-08	-2.86234E-07	1.35966E-14	2.33209E-07	0.000923	4.87
1:48:20 PM	35.7615683	-120.9009840	0.62415711	-2.11012024	-2.0944E-08	-2.84489E-07	1.34326E-14	2.31798E-07	0.000918	4.85
1:48:21 PM	35.7615665	-120.9010002	0.62415708	-2.11012052	-3.14159E-08	-2.82743E-07	1.34067E-14	2.31575E-07	0.000917	4.84
1:48:22 PM	35.7615653	-120.9010170	0.62415706	-2.11012082	-2.0944E-08	-2.93215E-07	1.42625E-14	2.38851E-07	0.000946	4.99
1:48:23 PM	35.7615648	-120.9010335	0.62415705	-2.11012110	-8.72665E-09	-2.87979E-07	1.36709E-14	2.33845E-07	0.000926	4.89
1:48:24 PM	35.7615642	-120.9010497	0.62415704	-2.11012139	-1.0472E-08	-2.82743E-07	1.31874E-14	2.29673E-07	0.000909	4.80
1:48:25 PM	35.7615632	-120.9010663	0.62415702	-2.11012168	-1.74533E-08	-2.89725E-07	1.3894E-14	2.35746E-07	0.000933	4.93
1:48:26 PM	35.7615630	-120.9010833	0.62415702	-2.11012197	-3.49066E-09	-2.96706E-07	1.44949E-14	2.40789E-07	0.000953	5.03
1:48:27 PM	35.7615627	-120.9011000	0.62415701	-2.11012226	-5.23599E-09	-2.9147E-07	1.39917E-14	2.36573E-07	0.000937	4.95
1:48:28 PM	35.7615623	-120.9011157	0.62415701	-2.11012254	-6.98132E-09	-2.74017E-07	1.23723E-14	2.22462E-07	0.000881	4.65
1:48:29 PM	35.7615625	-120.9011322	0.62415701	-2.11012283	3.49066E-09	-2.87979E-07	1.36549E-14	2.33709E-07	0.000925	4.89
1:48:30 PM	35.7615628	-120.9011493	0.62415702	-2.11012312	5.23599E-09	-2.98451E-07	1.46697E-14	2.42237E-07	0.000959	5.06
1:48:31 PM	35.7615630	-120.9011663	0.62415702	-2.11012342	3.49066E-09	-2.96706E-07	1.44949E-14	2.40789E-07	0.000953	5.03
1:48:32 PM	35.7615633	-120.9011830	0.62415703	-2.11012371	5.23599E-09	-2.9147E-07	1.39917E-14	2.36573E-07	0.000937	4.95
1:48:33 PM	35.7615643	-120.9011998	0.62415704	-2.11012401	1.74533E-08	-2.93215E-07	1.4229E-14	2.38571E-07	0.000945	4.99
1:48:34 PM	35.7615648	-120.9012173	0.62415705	-2.11012431	8.72665E-09	-3.05433E-07	1.53758E-14	2.47999E-07	0.000982	5.18
1:48:35 PM	35.7615660	-120.9012342	0.62415707	-2.11012461	2.0944E-08	-2.94961E-07	1.44315E-14	2.40262E-07	0.000951	5.02
1:48:36 PM	35.7615673	-120.9012510	0.62415710	-2.11012490	2.26893E-08	-2.93215E-07	1.42815E-14	2.39011E-07	0.000946	5.00
1:48:37 PM	35.7615683	-120.9012680	0.62415711	-2.11012520	1.74533E-08	-2.96706E-07	1.4568E-14	2.41396E-07	0.000956	5.05
1:48:38 PM	35.7615695	-120.9012853	0.62415713	-2.11012550	2.0944E-08	-3.01942E-07	1.51175E-14	2.45906E-07	0.000974	5.14
1:48:39 PM	35.7615708	-120.9013018	0.62415716	-2.11012579	2.26893E-08	-2.87979E-07	1.37806E-14	2.34781E-07	0.000929	4.91
1:48:40 PM	35.7615722	-120.9013180	0.62415718	-2.11012607	2.44346E-08	-2.82743E-07	1.33092E-14	2.30731E-07	0.000913	4.82
1:48:41 PM	35.7615742	-120.9013352	0.62415722	-2.11012637	3.49066E-08	-3.00197E-07	1.51394E-14	2.46085E-07	0.000974	5.14
1:48:42 PM	35.7615762	-120.9013517	0.62415725	-2.11012666	3.49066E-08	-2.87979E-07	1.39565E-14	2.36275E-07	0.000935	4.94
1:48:43 PM	35.7615783	-120.9013677	0.62415729	-2.11012694	3.66519E-08	-2.79253E-07	1.31729E-14	2.29546E-07	0.000909	4.80
1:48:44 PM	35.7615813	-120.9013847	0.62415734	-2.11012723	5.23599E-08	-2.96706E-07	1.51772E-14	2.46391E-07	0.000975	5.15
1:48:45 PM	35.7615843	-120.9014022	0.62415739	-2.11012754	5.23599E-08	-3.05433E-07	1.60422E-14	2.53316E-07	0.001003	5.30
1:48:46 PM	35.7615878	-120.9014188	0.62415745	-2.11012783	6.10865E-08	-2.89725E-07	1.47507E-14	2.42905E-07	0.000962	5.08
1:48:47 PM	35.7615920	-120.9014350	0.62415753	-2.11012811	7.33038E-08	-2.82743E-07	1.45033E-14	2.40859E-07	0.000954	5.03

1:48:48 PM	35.7615963	-120.9014515	0.62415760	-2.11012840	7.50492E-08	-2.87979E-07	1.506E-14	2.45438E-07	0.000972	5.13
1:48:49 PM	35.7616005	-120.9014680	0.62415767	-2.11012869	7.33038E-08	-2.87979E-07	1.49952E-14	2.4491E-07	0.000970	5.12
1:48:50 PM	35.7616050	-120.9014842	0.62415775	-2.11012897	7.85398E-08	-2.82743E-07	1.47021E-14	2.42504E-07	0.000960	5.07
1:48:51 PM	35.7616098	-120.9014998	0.62415784	-2.11012924	8.37758E-08	-2.72271E-07	1.39578E-14	2.36286E-07	0.000935	4.94
1:48:52 PM	35.7616148	-120.9015153	0.62415792	-2.11012951	8.72665E-08	-2.70526E-07	1.39511E-14	2.3623E-07	0.000935	4.94
1:48:53 PM	35.7616198	-120.9015313	0.62415801	-2.11012979	8.72665E-08	-2.79253E-07	1.47409E-14	2.42824E-07	0.000961	5.08
1:48:54 PM	35.7616250	-120.9015468	0.62415810	-2.11013006	9.07571E-08	-2.70526E-07	1.41065E-14	2.37541E-07	0.000940	4.97
1:48:55 PM	35.7616302	-120.9015608	0.62415819	-2.11013031	9.07571E-08	-2.44346E-07	1.18876E-14	2.1806E-07	0.000863	4.56
1:48:56 PM	35.7616363	-120.9015757	0.62415830	-2.11013057	1.06465E-07	-2.60054E-07	1.39663E-14	2.36358E-07	0.000936	4.94
1:48:57 PM	35.7616430	-120.9015910	0.62415842	-2.11013083	1.16937E-07	-2.67035E-07	1.51569E-14	2.46227E-07	0.000975	5.15
1:48:58 PM	35.7616497	-120.9016062	0.62415853	-2.11013110	1.16937E-07	-2.6529E-07	1.5004E-14	2.44981E-07	0.000970	5.12
1:48:59 PM	35.7616567	-120.9016200	0.62415866	-2.11013134	1.22173E-07	-2.40855E-07	1.32811E-14	2.30487E-07	0.000912	4.82
1:49:00 PM	35.7616642	-120.9016347	0.62415879	-2.11013160	1.309E-07	-2.56563E-07	1.51194E-14	2.45922E-07	0.000974	5.14
1:49:01 PM	35.7616718	-120.9016493	0.62415892	-2.11013185	1.32645E-07	-2.54818E-07	1.50875E-14	2.45662E-07	0.000973	5.14
1:49:02 PM	35.7616797	-120.9016618	0.62415906	-2.11013207	1.37881E-07	-2.18166E-07	1.25879E-14	2.24391E-07	0.000888	4.69
1:49:03 PM	35.7616877	-120.9016753	0.62415920	-2.11013231	1.39626E-07	-2.35619E-07	1.40127E-14	2.36751E-07	0.000937	4.95
1:49:04 PM	35.7616967	-120.9016887	0.62415935	-2.11013254	1.5708E-07	-2.33874E-07	1.51725E-14	2.46353E-07	0.000975	5.15
1:49:05 PM	35.7617062	-120.9017012	0.62415952	-2.11013276	1.65806E-07	-2.18166E-07	1.4708E-14	2.42553E-07	0.000960	5.07
1:49:06 PM	35.7617148	-120.9017137	0.62415967	-2.11013298	1.50098E-07	-2.18166E-07	1.34675E-14	2.32099E-07	0.000919	4.85
1:49:07 PM	35.7617245	-120.9017245	0.62415984	-2.11013316	1.69297E-07	-1.88496E-07	1.30142E-14	2.2816E-07	0.000903	4.77
1:49:08 PM	35.7617350	-120.9017348	0.62416002	-2.11013334	1.8326E-07	-1.79769E-07	1.37158E-14	2.34229E-07	0.000927	4.90
1:49:09 PM	35.7617462	-120.9017450	0.62416022	-2.11013352	1.95477E-07	-1.78024E-07	1.47698E-14	2.43062E-07	0.000962	5.08
1:49:10 PM	35.7617570	-120.9017557	0.62416041	-2.11013371	1.88496E-07	-1.8675E-07	1.46237E-14	2.41857E-07	0.000958	5.06
1:49:11 PM	35.7617683	-120.9017657	0.62416060	-2.11013388	1.97222E-07	-1.74533E-07	1.47386E-14	2.42805E-07	0.000961	5.08
1:49:12 PM	35.7617802	-120.9017747	0.62416081	-2.11013404	2.07694E-07	-1.5708E-07	1.48459E-14	2.43688E-07	0.000965	5.09
1:49:13 PM	35.7617917	-120.9017827	0.62416101	-2.11013418	2.00713E-07	-1.39626E-07	1.32807E-14	2.30483E-07	0.000912	4.82
1:49:14 PM	35.7618038	-120.9017900	0.62416122	-2.11013431	2.11185E-07	-1.27409E-07	1.3822E-14	2.35134E-07	0.000931	4.92
1:49:15 PM	35.7618162	-120.9017968	0.62416144	-2.11013443	2.16421E-07	-1.18682E-07	1.40282E-14	2.36881E-07	0.000938	4.95
1:49:16 PM	35.7618282	-120.9018030	0.62416165	-2.11013453	2.0944E-07	-1.0821E-07	1.28938E-14	2.27102E-07	0.000899	4.75
1:49:17 PM	35.7618405	-120.9018073	0.62416186	-2.11013461	2.14675E-07	-7.50492E-08	1.24486E-14	2.23146E-07	0.000883	4.66
1:49:18 PM	35.7618528	-120.9018112	0.62416208	-2.11013468	2.14675E-07	-6.80678E-08	1.22841E-14	2.21667E-07	0.000878	4.63
1:49:19 PM	35.7618653	-120.9018153	0.62416230	-2.11013475	2.18166E-07	-7.15585E-08	1.2742E-14	2.25761E-07	0.000894	4.72
1:49:20 PM	35.7618780	-120.9018180	0.62416252	-2.11013480	2.21657E-07	-4.71239E-08	1.26485E-14	2.24931E-07	0.000891	4.70
1:49:21 PM	35.7618907	-120.9018203	0.62416274	-2.11013484	2.21657E-07	-4.01426E-08	1.25482E-14	2.24037E-07	0.000887	4.68
1:49:22 PM	35.7619032	-120.9018227	0.62416296	-2.11013488	2.18166E-07	-4.18879E-08	1.21879E-14	2.20798E-07	0.000874	4.62
1:49:23 PM	35.7619163	-120.9018245	0.62416319	-2.11013491	2.28638E-07	-3.14159E-08	1.32313E-14	2.30055E-07	0.000911	4.81
1:49:24 PM	35.7619290	-120.9018257	0.62416341	-2.11013493	2.21657E-07	-2.0944E-08	1.23551E-14	2.22307E-07	0.000880	4.65
1:49:25 PM	35.7619417	-120.9018272	0.62416363	-2.11013496	2.21657E-07	-2.61799E-08	1.23958E-14	2.22672E-07	0.000882	4.65
1:49:26 PM	35.7619548	-120.9018277	0.62416386	-2.11013497	2.28638E-07	-8.72665E-09	1.30814E-14	2.28748E-07	0.000906	4.78
1:49:27 PM	35.7619678	-120.9018277	0.62416409	-2.11013497	2.26893E-07	0	1.28701E-14	2.26893E-07	0.000898	4.74
1:49:28 PM	35.7619798	-120.9018268	0.62416429	-2.11013495	2.0944E-07	1.5708E-08	1.10068E-14	2.09827E-07	0.000831	4.39
1:49:29 PM	35.7619927	-120.9018258	0.62416452	-2.11013493	2.25147E-07	1.74533E-08	1.2723E-14	2.25592E-07	0.000893	4.72
1:49:30 PM	35.7620055	-120.9018238	0.62416474	-2.11013490	2.23402E-07	3.49066E-08	1.26777E-14	2.25191E-07	0.000892	4.71
1:49:31 PM	35.7620180	-120.9018217	0.62416496	-2.11013486	2.18166E-07	3.66519E-08	1.21203E-14	2.20184E-07	0.000872	4.60
1:49:32 PM	35.7620305	-120.9018192	0.62416518	-2.11013482	2.18166E-07	4.36332E-08	1.22125E-14	2.21021E-07	0.000875	4.62
1:49:33 PM	35.7620428	-120.9018153	0.62416539	-2.11013475	2.14675E-07	6.80678E-08	1.22841E-14	2.21667E-07	0.000878	4.63
1:49:34 PM	35.7620552	-120.9018108	0.62416561	-2.11013467	2.16421E-07	7.85398E-08	1.27249E-14	2.25609E-07	0.000893	4.72
1:49:35 PM	35.7620673	-120.9018057	0.62416582	-2.11013458	2.11185E-07	8.90118E-08	1.2454E-14	2.23195E-07	0.000884	4.67
1:49:36 PM	35.7620793	-120.9018002	0.62416603	-2.11013449	2.0944E-07	9.59931E-08	1.24831E-14	2.23455E-07	0.000885	4.67
1:49:37 PM	35.7620925	-120.9017940	0.62416626	-2.11013438	2.30383E-07	1.0821E-07	1.51967E-14	2.4655E-07	0.000976	5.15
1:49:38 PM	35.7621035	-120.9017858	0.62416645	-2.11013423	1.91986E-07	1.43117E-07	1.25864E-14	2.24378E-07	0.000888	4.69
1:49:39 PM	35.7621138	-120.9017760	0.62416663	-2.11013406	1.79769E-07	1.71042E-07	1.2895E-14	2.27113E-07	0.000899	4.75
1:49:40 PM	35.7621238	-120.9017662	0.62416681	-2.11013389	1.74533E-07	1.71042E-07	1.24313E-14	2.22991E-07	0.000883	4.66
1:49:41 PM	35.7621330	-120.9017542	0.62416697	-2.11013368	1.6057E-07	2.0944E-07	1.36664E-14	2.33807E-07	0.000926	4.89
1:49:42 PM	35.7621417	-120.9017418	0.62416712	-2.11013347	1.51844E-07	2.16421E-07	1.34743E-14	2.32157E-07	0.000919	4.85
1:49:43 PM	35.7621488	-120.9017307	0.62416724	-2.11013327	1.23918E-07	1.93732E-07	1.00172E-14	2.00172E-07	0.000792	4.18
1:49:44 PM	35.7621548	-120.9017223	0.62416735	-2.11013313	1.0472E-07	1.46608E-07	6.27971E-15	1.58489E-07	0.000627	3.31
1:49:45 PM	35.7621585	-120.9017162	0.62416741	-2.11013302	6.45772E-08	1.06465E-07	2.90841E-15	1.07859E-07	0.000427	2.25
1:49:46 PM	35.7621617	-120.9017118	0.62416747	-2.11013294	5.58505E-08	7.67945E-08	1.75061E-15	8.36805E-08	0.000331	1.75
1:49:47 PM	35.7621648	-120.9017085	0.62416752	-2.11013288	5.41052E-08	5.75959E-08	1.27791E-15	7.14957E-08	0.000283	1.49
1:49:48 PM	35.7621678	-120.9017055	0.62416758	-2.11013283	5.23599E-08	5.23599E-08	1.13668E-15	6.74295E-08	0.000267	1.41
1:49:49 PM	35.7621705	-120.9017027	0.62416762	-2.11013278	4.71239E-08	4.88692E-08	9.48293E-16	6.15887E-08	0.000244	1.29
1:49:50 PM	35.7621725	-120.9017000	0.62416766	-2.11013274	3.49066E-08	4.71239E-08	6.70166E-16	5.17751E-08	0.000205	1.08
1:49:51 PM	35.7621745	-120.9016983	0.62416769	-2.11013271	3.49066E-08	2.96706E-08	4.49533E-16	4.24044E-08	0.000168	0.89
Run 3										
2:31:10 PM	35.7621728	-120.9016423	0.62416766	-2.11013173	--	--	--	--	--	--
2:31:11 PM	35.7621725	-120.9016435	0.62416766	-2.11013175	-5.23599E-09	-2.0944E-08	7.90611E-17	1.77833E-08	0.000070	0.37
2:31:12 PM	35.7621718	-120.9016492	0.62416765	-2.11013185	-1.22173E-08	-9.94838E-08	1.66649E-15	8.16454E-08	0.000323	1.71
2:31:13 PM	35.7621750	-120.9016533	0.62416770	-2.11013192	5.58505E-08	-7.15585E-08	1.62274E-15	8.05665E-08	0.000319	1.68
2:31:14 PM	35.7621805	-120.9016508	0.62416780	-2.11013188	9.59931E-08	4.36332E-08	2.61707E-15	1.02315E-07	0.000405	2.14
2:31:15 PM	35.7621852	-120.9016420	0.62416788	-2.11013172	8.20305E-08	1.53589E-07	5.56539E-15	1.49203E-07	0.000591	3.12
2:31:16 PM	35.7621872	-120.9016293	0.62416791	-2.11013150	3.49066E-08	2.21657E-07	8.39232E-15	1.83219E-07	0.000725	3.83
2:31:17 PM	35.7621878	-120.9016148	0.62416792	-2.11013125	1.0472E-08	2.53073E-07	1.05702E-14	2.05623E-07	0.000814	4.30
2:31:18 PM	35.7621875	-120.9015990	0.62416792	-2.11013097	-5.23599E-09	2.75762E-07	1.25248E-14	2.23828E-07	0.000886	4.68
2:31:19 PM	35.7621872	-120.9015827	0.62416791	-2.11013069	-5.23599E-09	2.84489E-07	1.33296E-14	2.30908E-07	0.000914	4.83
2:31:20 PM	35.7621870	-120.9015670	0.62416791	-2.11013041	-3.49066E-09	2.74017E-07	1.2363E-14	2.22378E-07	0.000880	4.65
2:31:21 PM	35.7621870	-120.9015508	0.62416791	-2.11013013	0	2.82743E-07	1.31598E-14	2.29432E-07	0.000908	4.80
2:31:22 PM	35.7621875	-120.9015350	0.62416792	-2.11012986	8.72665E-09	2.75762E-07	1.2537E-14	2.23937E-07	0.000887	4.68
2:31:23 PM	35.7621887	-120.9015188	0.62416794	-2.11012957	2.0944E-08	2.82743E-07	1.32694E-14	2.30386E-07	0.000912	4.82
2:31:24 PM	35.7621902	-120.9015030	0.62416797	-2.11012930	2.61799E-08	2.75762E-07	1.26893E-14	2.25293E-07	0.000892	4.71
2:31:25 PM	35.7621918	-120.9014875	0.62416799	-2.11012903	2.79253E-08	2.70526E-07	1.2242E-14	2.21287E-07	0.000876	4.63
2:31:26 PM	35.7621940	-120.9014723	0.62416803	-2.11012876	3.83972E-08	2.6529E-07	1.19538E-14	2.18667E-07	0.000866	4.57
2:31:27 PM	35.7621962	-120.9014572	0.62416807	-2.11012850	3.83972E-08	2.63545E-07	1.18019E-14	2.17273E-07	0.000860	4.54
2:31:28 PM	35.7621988	-120.9014423	0.62416812	-2.11012824	4.53786E-08	2.60054E-07	1.16472E-14	2.15845E-07	0.000855	4.51

2:31:29 PM	35.7622020	-120.9014268	0.62416817	-2.11012797	5.58505E-08	2.70526E-07	1.28269E-14	2.26512E-07	0.000897	4.73	
2:31:30 PM	35.7622055	-120.9014117	0.62416823	-2.11012770	6.10865E-08	2.63545E-07	1.23662E-14	2.22407E-07	0.000881	4.65	
2:31:31 PM	35.7622088	-120.9013965	0.62416829	-2.11012744	5.75959E-08	2.6529E-07	1.24146E-14	2.22841E-07	0.000882	4.66	
2:31:32 PM	35.7622125	-120.9013812	0.62416836	-2.11012717	6.45772E-08	2.67035E-07	1.27807E-14	2.26104E-07	0.000895	4.73	
2:31:33 PM	35.7622162	-120.9013655	0.62416842	-2.11012690	6.45772E-08	2.74017E-07	1.34025E-14	2.31538E-07	0.000917	4.84	
2:31:34 PM	35.7622200	-120.9013502	0.62416849	-2.11012663	6.63225E-08	2.67035E-07	1.28378E-14	2.26608E-07	0.000897	4.74	
2:31:35 PM	35.7622238	-120.9013348	0.62416855	-2.11012636	6.63225E-08	2.68781E-07	1.29918E-14	2.27963E-07	0.000903	4.77	
2:31:36 PM	35.7622277	-120.9013195	0.62416862	-2.11012610	6.80678E-08	2.67035E-07	1.28965E-14	2.27125E-07	0.000899	4.75	
2:31:37 PM	35.7622315	-120.9013042	0.62416869	-2.11012583	6.63225E-08	2.67035E-07	1.28378E-14	2.26608E-07	0.000897	4.74	
2:31:38 PM	35.7622350	-120.9012888	0.62416875	-2.11012556	6.10865E-08	2.68781E-07	1.2825E-14	2.26495E-07	0.000897	4.73	
2:31:39 PM	35.7622387	-120.9012733	0.62416881	-2.11012529	6.45772E-08	2.70526E-07	1.30896E-14	2.2882E-07	0.000906	4.78	
2:31:40 PM	35.7622425	-120.9012577	0.62416888	-2.11012502	6.63225E-08	2.72271E-07	1.33027E-14	2.30674E-07	0.000913	4.82	
2:31:41 PM	35.7622458	-120.9012425	0.62416894	-2.11012475	5.75959E-08	2.6529E-07	1.24145E-14	2.22841E-07	0.000882	4.66	
2:31:42 PM	35.7622492	-120.9012273	0.62416900	-2.11012449	5.93412E-08	2.6529E-07	1.24656E-14	2.23299E-07	0.000884	4.67	
2:31:43 PM	35.7622525	-120.9012122	0.62416905	-2.11012422	5.75959E-08	2.63545E-07	1.22626E-14	2.21473E-07	0.000877	4.63	
2:31:44 PM	35.7622558	-120.9011970	0.62416911	-2.11012396	5.75959E-08	2.6529E-07	1.24145E-14	2.22841E-07	0.000882	4.66	
2:31:45 PM	35.7622590	-120.9011818	0.62416917	-2.11012369	5.58505E-08	2.6529E-07	1.2365E-14	2.22396E-07	0.000880	4.65	
2:31:46 PM	35.7622622	-120.9011668	0.62416922	-2.11012343	5.58505E-08	2.61799E-07	1.20622E-14	2.19656E-07	0.000870	4.59	
2:31:47 PM	35.7622655	-120.9011512	0.62416928	-2.11012316	5.75959E-08	2.72271E-07	1.30323E-14	2.28318E-07	0.000904	4.77	
2:31:48 PM	35.7622690	-120.9011358	0.62416934	-2.11012289	6.10865E-08	2.68781E-07	1.2825E-14	2.26495E-07	0.000897	4.73	
2:31:49 PM	35.7622722	-120.9011203	0.62416940	-2.11012262	5.58505E-08	2.70526E-07	1.28269E-14	2.26511E-07	0.000897	4.73	
2:31:50 PM	35.7622755	-120.9011050	0.62416946	-2.11012235	5.75959E-08	2.67035E-07	1.25675E-14	2.2421E-07	0.000888	4.69	
2:31:51 PM	35.7622790	-120.9010898	0.62416952	-2.11012209	6.10865E-08	2.6529E-07	1.25181E-14	2.23769E-07	0.000886	4.68	
2:31:52 PM	35.7622823	-120.9010745	0.62416957	-2.11012182	5.75959E-08	2.67035E-07	1.25675E-14	2.24209E-07	0.000888	4.69	
2:31:53 PM	35.7622857	-120.9010592	0.62416963	-2.11012155	5.93412E-08	2.67035E-07	1.26185E-14	2.24664E-07	0.000889	4.70	
2:31:54 PM	35.7622888	-120.9010438	0.62416969	-2.11012128	5.41052E-08	2.68781E-07	1.26239E-14	2.24713E-07	0.000890	4.70	
2:31:55 PM	35.7622920	-120.9010287	0.62416974	-2.11012102	5.58505E-08	2.63545E-07	1.22131E-14	2.21026E-07	0.000875	4.62	
2:31:56 PM	35.7622948	-120.9010135	0.62416979	-2.11012075	4.88692E-08	2.6529E-07	1.21823E-14	2.20747E-07	0.000874	4.61	
2:31:57 PM	35.7622977	-120.9009982	0.62416984	-2.11012049	5.06145E-08	2.67035E-07	1.23786E-14	2.22518E-07	0.000881	4.65	
2:31:58 PM	35.7623003	-120.9009830	0.62416989	-2.11012022	4.53786E-08	2.6529E-07	1.21E-14	2.2E-07	0.000871	4.60	
2:31:59 PM	35.7623027	-120.9009682	0.62416993	-2.11011996	4.18879E-08	2.58309E-07	1.14221E-14	2.13749E-07	0.000846	4.47	
2:32:00 PM	35.7623052	-120.9009532	0.62416997	-2.11011970	4.36332E-08	2.61799E-07	1.17583E-14	2.16871E-07	0.000859	4.53	
2:32:01 PM	35.7623080	-120.9009377	0.62417002	-2.11011943	4.88692E-08	2.70526E-07	1.26441E-14	2.24892E-07	0.000890	4.70	
2:32:02 PM	35.7623105	-120.9009227	0.62417007	-2.11011917	4.36332E-08	2.61799E-07	1.17583E-14	2.16871E-07	0.000859	4.53	
2:32:03 PM	35.7623127	-120.9009077	0.62417010	-2.11011891	3.83972E-08	2.61799E-07	1.16509E-14	2.15879E-07	0.000855	4.51	
2:32:04 PM	35.7623150	-120.9008925	0.62417014	-2.11011864	4.01426E-08	2.6529E-07	1.19881E-14	2.1898E-07	0.000867	4.58	
2:32:05 PM	35.7623173	-120.9008775	0.62417019	-2.11011838	4.01426E-08	2.61799E-07	1.16852E-14	2.16196E-07	0.000856	4.52	
2:32:06 PM	35.7623198	-120.9008623	0.62417023	-2.11011812	4.36332E-08	2.6529E-07	1.20612E-14	2.19647E-07	0.000870	4.59	
2:32:07 PM	35.7623220	-120.9008470	0.62417027	-2.11011785	3.83972E-08	2.67035E-07	1.21067E-14	2.20061E-07	0.000871	4.60	
2:32:08 PM	35.7623243	-120.9008315	0.62417031	-2.11011758	4.01426E-08	2.70526E-07	1.24499E-14	2.23158E-07	0.000883	4.66	
2:32:09 PM	35.7623268	-120.9008162	0.62417035	-2.11011731	4.36332E-08	2.67035E-07	1.22141E-14	2.21035E-07	0.000875	4.62	
2:32:10 PM	35.7623293	-120.9008005	0.62417039	-2.11011704	4.36332E-08	2.74017E-07	1.28359E-14	2.26591E-07	0.000897	4.74	
2:32:11 PM	35.7623320	-120.9007848	0.62417044	-2.11011676	4.71239E-08	2.74017E-07	1.29151E-14	2.27289E-07	0.000900	4.75	
2:32:12 PM	35.7623345	-120.9007693	0.62417049	-2.11011649	4.36332E-08	2.70526E-07	1.2523E-14	2.23812E-07	0.000886	4.68	
2:32:13 PM	35.7623367	-120.9007535	0.62417052	-2.11011622	3.83972E-08	2.75762E-07	1.28865E-14	2.27037E-07	0.000899	4.75	
2:32:14 PM	35.7623390	-120.9007377	0.62417056	-2.11011594	4.01426E-08	2.75762E-07	1.29207E-14	2.27339E-07	0.000900	4.75	
2:32:15 PM	35.7623412	-120.9007222	0.62417060	-2.11011567	3.83972E-08	2.70526E-07	1.24156E-14	2.22851E-07	0.000882	4.66	
2:32:16 PM	35.7623435	-120.9007063	0.62417064	-2.11011539	4.01426E-08	2.77507E-07	1.30797E-14	2.28733E-07	0.000906	4.78	
2:32:17 PM	35.7623457	-120.9006903	0.62417068	-2.11011511	3.83972E-08	2.79253E-07	1.32054E-14	2.29829E-07	0.000910	4.80	
2:32:18 PM	35.7623480	-120.9006742	0.62417072	-2.11011483	4.01426E-08	2.80998E-07	1.34006E-14	2.31522E-07	0.000917	4.84	
2:32:19 PM	35.7623503	-120.9006582	0.62417076	-2.11011455	4.01426E-08	2.79253E-07	1.32396E-14	2.30127E-07	0.000911	4.81	
2:32:20 PM	35.7623525	-120.9006422	0.62417080	-2.11011427	3.83972E-08	2.79253E-07	1.32054E-14	2.29829E-07	0.000910	4.80	
2:32:21 PM	35.7623548	-120.9006262	0.62417084	-2.11011399	4.01426E-08	2.79253E-07	1.32396E-14	2.30127E-07	0.000911	4.81	
2:32:22 PM	35.7623567	-120.9006103	0.62417087	-2.11011372	3.31613E-08	2.77507E-07	1.29517E-14	2.27611E-07	0.000901	4.76	
2:32:23 PM	35.7623587	-120.9005945	0.62417091	-2.11011344	3.49066E-08	2.75762E-07	1.28225E-14	2.26473E-07	0.000897	4.73	
2:32:24 PM	35.7623605	-120.9005785	0.62417094	-2.11011316	3.14159E-08	2.79253E-07	1.30835E-14	2.28766E-07	0.000906	4.78	
2:32:25 PM	35.7623620	-120.9005625	0.62417097	-2.11011288	2.61799E-08	2.79253E-07	1.30081E-14	2.28106E-07	0.000903	4.77	
2:32:26 PM	35.7623637	-120.9005467	0.62417099	-2.11011261	2.96706E-08	2.75762E-07	1.27379E-14	2.25725E-07	0.000894	4.72	
2:32:27 PM	35.7623652	-120.9005308	0.62417102	-2.11011233	2.61799E-08	2.77507E-07	1.28482E-14	2.26699E-07	0.000898	4.74	
2:32:28 PM	35.7623667	-120.9005148	0.62417105	-2.11011205	2.61799E-08	2.79253E-07	1.30081E-14	2.28106E-07	0.000903	4.77	
2:32:29 PM	35.7623678	-120.9004987	0.62417107	-2.11011177	1.91986E-08	2.80998E-07	1.30899E-14	2.28822E-07	0.000906	4.78	
2:32:30 PM	35.7623687	-120.9004827	0.62417108	-2.11011149	1.5708E-08	2.79253E-07	1.28985E-14	2.27143E-07	0.000899	4.75	
2:32:31 PM	35.7623695	-120.9004668	0.62417110	-2.11011121	1.39626E-08	2.77507E-07	1.27256E-14	2.25615E-07	0.000893	4.72	
2:32:32 PM	35.7623703	-120.9004507	0.62417111	-2.11011093	1.39626E-08	2.80998E-07	1.30465E-14	2.28442E-07	0.000904	4.78	
2:32:33 PM	35.7623713	-120.9004348	0.62417113	-2.11011065	1.74533E-08	2.77507E-07	1.2753E-14	2.25858E-07	0.000894	4.72	
2:32:34 PM	35.7623723	-120.9004193	0.62417114	-2.11011038	1.74533E-08	2.70526E-07	1.21232E-14	2.2021E-07	0.000872	4.60	
2:32:35 PM	35.7623732	-120.9004035	0.62417116	-2.11011011	1.5708E-08	2.75762E-07	1.25795E-14	2.24317E-07	0.000888	4.69	
2:32:36 PM	35.7623743	-120.9003875	0.62417118	-2.11010983	1.91986E-08	2.79253E-07	1.29289E-14	2.27411E-07	0.000900	4.75	
2:32:37 PM	35.7623752	-120.9003715	0.62417120	-2.11010955	1.5708E-08	2.79253E-07	1.28985E-14	2.27143E-07	0.000899	4.75	
2:32:38 PM	35.7623760	-120.9003557	0.62417121	-2.11010927	1.39626E-08	2.75762E-07	1.25666E-14	2.24202E-07	0.000888	4.69	
2:32:39 PM	35.7623767	-120.9003403	0.62417122	-2.11010901	1.22173E-08	2.68781E-07	1.19294E-14	2.18443E-07	0.000865	4.57	
2:32:40 PM	35.7623770	-120.9003250	0.62417123	-2.11010874	5.23599E-09	2.67035E-07	1.1745E-14	2.16749E-07	0.000858	4.53	
2:32:41 PM	35.7623770	-120.9003090	0.62417123	-2.11010846	0	2.79253E-07	1.28368E-14	2.26599E-07	0.000897	4.74	
2:32:42 PM	35.7623770	-120.9002933	0.62417123	-2.11010818	0	2.74017E-07	1.23599E-14	2.2235E-07	0.000880	4.65	
2:32:43 PM	35.7623770	-120.9002778	0.62417123	-2.11010791	0	2.70526E-07	1.2047E-14	2.19518E-07	0.000869	4.59	
2:32:44 PM	35.7623767	-120.9002623	0.62417122	-2.11010764	-5.23599E-09	2.70526E-07	1.20539E-14	2.1958E-07	0.000869	4.59	
2:32:45 PM	35.7623760	-120.9002467	0.62417121	-2.11010737	-1.22173E-08	2.72271E-07	1.22403E-14	2.21272E-07	0.000876	4.63	
2:32:46 PM	35.7623747	-120.9002318	0.62417119	-2.11010711	-2.26893E-08	2.60054E-07	1.12611E-14	2.12237E-07	0.000840	4.44	
2:32:47 PM	35.7623735	-120.9002163	0.62417117	-2.11010684	-2.0944E-08	2.70526E-07	1.21567E-14	2.20515E-07	0.000873	4.61	
2:32:48 PM	35.7623720	-120.9002008	0.62417114	-2.11010657	-2.61799E-08	2.70526E-07	1.22184E-14	2.21073E-07	0.000875	4.62	
2:32:49 PM	35.7623702	-120.9001855	0.62417111	-2.11010630	-3.14159E-08	2.67035E-07	1.19849E-14	2.18951E-07	0.000867	4.58	
2:32:50 PM	35.7623682	-120.9001707	0.62417107	-2.11010604	-3.49066E-08	2.58309E-07	1.12881E-14	2.12491E-07	0.000841	4.44	
2:32:51 PM	35.7623658	-120.9001555	0.62417103	-2.11010578	-4.18879E-08	2.6529E-07	1.20238E-14	2.19307E-07	0.000868	4.58	
2:32:52 PM	35.7623635	-120.9001403	0.62417099	-2.11010551	-4.01426E-08	2.6529E-07	1.1988E-14	2.1898E-07	0.000867	4.58	

2:32:53 PM	35.7623608	-120.9001250	0.62417094	-2.11010525	-4.71239E-08	2.67035E-07	1.22933E-14	2.2175E-07	0.000878	4.64
2:32:54 PM	35.7623578	-120.9001097	0.62417089	-2.11010498	-5.23599E-08	2.67035E-07	1.24235E-14	2.22922E-07	0.000883	4.66
2:32:55 PM	35.7623550	-120.9000943	0.62417084	-2.11010471	-4.88692E-08	2.68781E-07	1.24891E-14	2.23509E-07	0.000885	4.67
2:32:56 PM	35.7623517	-120.9000788	0.62417079	-2.11010444	-5.75959E-08	2.70526E-07	1.28763E-14	2.26948E-07	0.000898	4.74
2:32:57 PM	35.7623483	-120.9000637	0.62417073	-2.11010418	-5.93412E-08	2.63545E-07	1.23136E-14	2.21933E-07	0.000879	4.64
2:32:58 PM	35.7623447	-120.9000482	0.62417066	-2.11010391	-6.28319E-08	2.70526E-07	1.3034E-14	2.28333E-07	0.000904	4.77
2:32:59 PM	35.7623410	-120.9000327	0.62417060	-2.11010364	-6.45772E-08	2.70526E-07	1.30896E-14	2.28819E-07	0.000906	4.78
2:33:00 PM	35.7623372	-120.9000175	0.62417053	-2.11010337	-6.63225E-08	2.6529E-07	1.26849E-14	2.25254E-07	0.000892	4.71
2:33:01 PM	35.7623332	-120.9000030	0.62417046	-2.11010312	-6.98132E-08	2.53073E-07	1.17612E-14	2.16898E-07	0.000859	4.53
2:33:02 PM	35.7623290	-120.8999880	0.62417039	-2.11010286	-7.33038E-08	2.61799E-07	1.26257E-14	2.24728E-07	0.000890	4.70
2:33:03 PM	35.7623245	-120.8999733	0.62417031	-2.11010260	-7.85398E-08	2.56563E-07	1.23777E-14	2.2251E-07	0.000881	4.65
2:33:04 PM	35.7623190	-120.8999592	0.62417021	-2.11010235	-9.59931E-08	2.46091E-07	1.22727E-14	2.21565E-07	0.000877	4.63
2:33:05 PM	35.7623130	-120.8999460	0.62417011	-2.11010212	-1.0472E-07	2.30383E-07	1.14786E-14	2.14276E-07	0.000848	4.48
2:33:06 PM	35.7623052	-120.8999357	0.62416997	-2.11010194	-1.36136E-07	1.79769E-07	9.95298E-15	1.99529E-07	0.000790	4.17
2:33:07 PM	35.7622977	-120.8999290	0.62416984	-2.11010183	-1.309E-07	1.16937E-07	6.53463E-15	1.61674E-07	0.000640	3.38
2:33:08 PM	35.7622903	-120.8999275	0.62416971	-2.11010180	-1.29154E-07	2.61799E-08	4.28304E-15	1.3089E-07	0.000518	2.74
2:33:09 PM	35.7622838	-120.8999278	0.62416960	-2.11010181	-1.13446E-07	-5.23599E-09	3.22203E-15	1.13526E-07	0.000449	2.37
2:33:10 PM	35.7622787	-120.8999302	0.62416951	-2.11010185	-8.90118E-08	-4.18879E-08	2.2696E-15	9.52807E-08	0.000377	1.99
2:33:11 PM	35.7622775	-120.8999332	0.62416949	-2.11010190	-2.0944E-08	-5.23599E-08	5.60956E-16	4.7369E-08	0.000188	0.99
2:33:12 PM	35.7622800	-120.8999323	0.62416953	-2.11010188	4.36332E-08	1.5708E-08	5.16581E-16	4.54568E-08	0.000180	0.95
Run 4										
2:35:02 PM	35.7622972	-120.9000957	0.62416983	-2.11010474	--	--	--	--	--	--
2:35:03 PM	35.7622973	-120.9000967	0.62416984	-2.11010475	1.74533E-09	-1.74533E-08	5.09053E-17	1.42696E-08	0.000056	0.30
2:35:04 PM	35.7622972	-120.9000980	0.62416983	-2.11010478	-1.74533E-09	-2.26893E-08	8.55045E-17	1.84937E-08	0.000073	0.39
2:35:05 PM	35.7622975	-120.9000990	0.62416984	-2.11010479	5.23599E-09	-1.74533E-08	5.69976E-17	1.50994E-08	0.000060	0.32
2:35:06 PM	35.7622977	-120.9001005	0.62416984	-2.11010482	3.49066E-09	-2.61799E-08	1.1587E-16	2.15285E-08	0.000085	0.45
2:35:07 PM	35.7622978	-120.9001017	0.62416984	-2.11010484	1.74533E-09	-2.0944E-08	7.29685E-17	1.70843E-08	0.000068	0.36
2:35:08 PM	35.7622985	-120.9001032	0.62416986	-2.11010487	1.22173E-08	-2.61799E-08	1.50139E-16	2.45062E-08	0.000097	0.51
2:35:09 PM	35.7623032	-120.9001080	0.62416994	-2.11010495	8.20305E-08	-8.37758E-08	2.83756E-15	1.06538E-07	0.000422	2.23
2:35:10 PM	35.7623092	-120.9001183	0.62417004	-2.11010513	1.0472E-07	-1.79769E-07	8.06131E-15	1.7957E-07	0.000711	3.75
2:35:11 PM	35.7623137	-120.9001322	0.62417012	-2.11010537	7.85398E-08	-2.42601E-07	1.12304E-14	2.11947E-07	0.000839	4.43
2:35:12 PM	35.7623167	-120.9001473	0.62417017	-2.11010564	5.23599E-08	-2.63545E-07	1.21187E-14	2.2017E-07	0.000872	4.60
2:35:13 PM	35.7623173	-120.9001638	0.62417019	-2.11010592	1.0472E-08	-2.87979E-07	1.3679E-14	2.33915E-07	0.000926	4.89
2:35:14 PM	35.7623165	-120.9001808	0.62417017	-2.11010622	-1.39626E-08	-2.96706E-07	1.45403E-14	2.41166E-07	0.000955	5.04
2:35:15 PM	35.7623143	-120.9001973	0.62417013	-2.11010651	-3.83972E-08	-2.87979E-07	1.40202E-14	2.36814E-07	0.000938	4.95
2:35:16 PM	35.7623110	-120.9002137	0.62417008	-2.11010680	-5.75959E-08	-2.86234E-07	1.4316E-14	2.39299E-07	0.000947	5.00
2:35:17 PM	35.7623063	-120.9002302	0.62416999	-2.11010708	-8.20305E-08	-2.87979E-07	1.53339E-14	2.4766E-07	0.000980	5.18
2:35:18 PM	35.7623008	-120.9002462	0.62416990	-2.11010736	-9.59931E-08	-2.79253E-07	1.51405E-14	2.46093E-07	0.000974	5.14
2:35:19 PM	35.7622947	-120.9002618	0.62416979	-2.11010763	-1.06465E-07	-2.72271E-07	1.50367E-14	2.45248E-07	0.000971	5.13
2:35:20 PM	35.7622878	-120.9002770	0.62416967	-2.11010790	-1.20428E-07	-2.6529E-07	1.52109E-14	2.46665E-07	0.000977	5.16
2:35:21 PM	35.7622803	-120.9002917	0.62416954	-2.11010816	-1.309E-07	-2.56563E-07	1.51192E-14	2.45921E-07	0.000974	5.14
2:35:22 PM	35.7622725	-120.9003060	0.62416940	-2.11010841	-1.36136E-07	-2.49582E-07	1.48871E-14	2.44026E-07	0.000966	5.10
2:35:23 PM	35.7622645	-120.9003200	0.62416926	-2.11010865	-1.39626E-07	-2.44346E-07	1.47021E-14	2.42504E-07	0.000960	5.07
2:35:24 PM	35.7622562	-120.9003338	0.62416912	-2.11010889	-1.44862E-07	-2.40855E-07	1.47957E-14	2.43275E-07	0.000963	5.09
2:35:25 PM	35.7622478	-120.9003475	0.62416897	-2.11010913	-1.46608E-07	-2.3911E-07	1.47849E-14	2.43187E-07	0.000963	5.08
2:35:26 PM	35.7622393	-120.9003613	0.62416882	-2.11010937	-1.48353E-07	-2.40855E-07	1.50515E-14	2.45369E-07	0.000971	5.13
2:35:27 PM	35.7622308	-120.9003753	0.62416868	-2.11010962	-1.48353E-07	-2.44346E-07	1.53303E-14	2.47632E-07	0.000980	5.18
2:35:28 PM	35.7622225	-120.9003892	0.62416853	-2.11010986	-1.44862E-07	-2.42601E-07	1.49346E-14	2.44414E-07	0.000968	5.11
2:35:29 PM	35.7622140	-120.9004030	0.62416838	-2.11011010	-1.48353E-07	-2.40855E-07	1.50515E-14	2.45369E-07	0.000971	5.13
2:35:30 PM	35.7622057	-120.9004167	0.62416824	-2.11011034	-1.44862E-07	-2.3911E-07	1.46578E-14	2.42139E-07	0.000959	5.06
2:35:31 PM	35.7621973	-120.9004302	0.62416809	-2.11011057	-1.46608E-07	-2.35619E-07	1.45122E-14	2.40933E-07	0.000954	5.04
2:35:32 PM	35.7621890	-120.9004440	0.62416795	-2.11011081	-1.44862E-07	-2.40855E-07	1.47957E-14	2.43275E-07	0.000963	5.09
2:35:33 PM	35.7621807	-120.9004577	0.62416780	-2.11011105	-1.44862E-07	-2.3911E-07	1.46578E-14	2.42139E-07	0.000959	5.06
2:35:34 PM	35.7621723	-120.9004713	0.62416765	-2.11011129	-1.46608E-07	-2.37365E-07	1.46481E-14	2.42058E-07	0.000958	5.06
2:35:35 PM	35.7621638	-120.9004850	0.62416751	-2.11011153	-1.48353E-07	-2.3911E-07	1.49137E-14	2.44243E-07	0.000967	5.11
2:35:36 PM	35.7621553	-120.9004988	0.62416736	-2.11011177	-1.48353E-07	-2.40855E-07	1.50516E-14	2.4537E-07	0.000971	5.13
2:35:37 PM	35.7621468	-120.9005128	0.62416721	-2.11011202	-1.48353E-07	-2.44346E-07	1.53304E-14	2.47632E-07	0.000980	5.18
2:35:38 PM	35.7621385	-120.9005270	0.62416706	-2.11011226	-1.44862E-07	-2.47837E-07	1.53573E-14	2.47849E-07	0.000981	5.18
2:35:39 PM	35.7621302	-120.9005412	0.62416692	-2.11011251	-1.44862E-07	-2.47837E-07	1.53573E-14	2.47849E-07	0.000981	5.18
2:35:40 PM	35.7621220	-120.9005553	0.62416678	-2.11011276	-1.43117E-07	-2.46091E-07	1.50897E-14	2.45681E-07	0.000973	5.14
2:35:41 PM	35.7621137	-120.9005692	0.62416663	-2.11011300	-1.44862E-07	-2.42601E-07	1.49346E-14	2.44414E-07	0.000968	5.11
2:35:42 PM	35.7621058	-120.9005832	0.62416649	-2.11011324	-1.37881E-07	-2.44346E-07	1.4581E-14	2.41504E-07	0.000956	5.05
2:35:43 PM	35.7620978	-120.9005973	0.62416635	-2.11011349	-1.39626E-07	-2.46091E-07	1.4843E-14	2.43664E-07	0.000965	5.09
2:35:44 PM	35.7620900	-120.9006115	0.62416622	-2.11011374	-1.36136E-07	-2.47837E-07	1.47443E-14	2.42852E-07	0.000961	5.08
2:35:45 PM	35.7620820	-120.9006258	0.62416608	-2.11011399	-1.39626E-07	-2.49582E-07	1.51278E-14	2.4599E-07	0.000974	5.14
2:35:46 PM	35.7620742	-120.9006398	0.62416594	-2.11011423	-1.36136E-07	-2.44346E-07	1.44615E-14	2.40512E-07	0.000952	5.03
2:35:47 PM	35.7620663	-120.9006540	0.62416580	-2.11011448	-1.37881E-07	-2.47837E-07	1.48638E-14	2.43835E-07	0.000965	5.10
2:35:48 PM	35.7620585	-120.9006683	0.62416567	-2.11011473	-1.36136E-07	-2.49582E-07	1.48872E-14	2.44026E-07	0.000966	5.10
2:35:49 PM	35.7620507	-120.9006827	0.62416553	-2.11011498	-1.36136E-07	-2.51327E-07	1.50311E-14	2.45203E-07	0.000971	5.13
2:35:50 PM	35.7620430	-120.9006973	0.62416540	-2.11011524	-1.3439E-07	-2.54818E-07	1.52039E-14	2.46608E-07	0.000976	5.15
2:35:51 PM	35.7620355	-120.9007118	0.62416527	-2.11011549	-1.309E-07	-2.53073E-07	1.48265E-14	2.43528E-07	0.000964	5.09
2:35:52 PM	35.7620280	-120.9007265	0.62416514	-2.11011575	-1.309E-07	-2.56563E-07	1.51193E-14	2.45921E-07	0.000974	5.14
2:35:53 PM	35.7620207	-120.9007408	0.62416501	-2.11011600	-1.27409E-07	-2.49582E-07	1.43122E-14	2.39267E-07	0.000947	5.00
2:35:54 PM	35.7620133	-120.9007558	0.62416488	-2.11011626	-1.29154E-07	-2.61799E-07	1.54526E-14	2.48617E-07	0.000984	5.20
2:35:55 PM	35.7620058	-120.9007708	0.62416475	-2.11011652	-1.309E-07	-2.61799E-07	1.55661E-14	2.49528E-07	0.000988	5.22
2:35:56 PM	35.7619988	-120.9007860	0.62416463	-2.11011678	-1.22173E-07	-2.6529E-07	1.53169E-14	2.47523E-07	0.000980	5.17
2:35:57 PM	35.7619922	-120.9008010	0.62416451	-2.11011705	-1.15192E-07	-2.61799E-07	1.45997E-14	2.41659E-07	0.000957	5.05
2:35:58 PM	35.7619857	-120.9008165	0.62416440	-2.11011732	-1.13446E-07	-2.70526E-07	1.52646E-14	2.471E-07	0.000978	5.17
2:35:59 PM	35.7619793	-120.9008318	0.62416429	-2.11011758	-1.11701E-07	-2.67035E-07	1.48575E-14	2.43783E-07	0.000965	5.10
2:36:00 PM	35.7619730	-120.9008473	0.62416418	-2.11011785	-1.09956E-07	-2.70526E-07	1.50697E-14	2.45517E-07	0.000972	5.13
2:36:01 PM	35.7619668	-120.9008628	0.62416407	-2.11011812	-1.0821E-07	-2.70526E-07	1.49745E-14	2.44741E-07	0.000969	5.12
2:36:02 PM	35.7619610	-120.9008783	0.62416397	-2.11011839	-1.01229E-07	-2.70526E-07	1.4609E-14	2.41735E-07	0.000957	5.05
2:36:03 PM	35.7619552	-120.9008933	0.62416387	-2.11011866	-1.01229E-07	-2.61799E-07	1.38443E-14	2.35323E-07	0.000932	4.92
2:36:04 PM	35.7619493	-120.9009087	0.62416376	-2.11011893	-1.02974E-07	-2.68781E-07	1.45431E-14	2.4119E-07	0.000955	5.04

2:36:05 PM	35.7619437	-120.9009242	0.62416366	-2.11011920	-9.77384E-08	-2.70526E-07	1.44353E-14	2.40294E-07	0.000951	5.02
2:36:06 PM	35.7619382	-120.9009397	0.62416357	-2.11011947	-9.59931E-08	-2.70526E-07	1.43508E-14	2.3959E-07	0.000949	5.01
2:36:07 PM	35.7619328	-120.9009550	0.62416347	-2.11011973	-9.42478E-08	-2.67035E-07	1.39589E-14	2.36296E-07	0.000935	4.94
2:36:08 PM	35.7619278	-120.9009705	0.62416339	-2.11012000	-8.72665E-08	-2.70526E-07	1.3951E-14	2.36229E-07	0.000935	4.94
2:36:09 PM	35.7619227	-120.9009858	0.62416330	-2.11012027	-8.90118E-08	-2.67035E-07	1.3719E-14	2.34257E-07	0.000927	4.90
2:36:10 PM	35.7619178	-120.9010018	0.62416321	-2.11012055	-8.55211E-08	-2.79253E-07	1.46654E-14	2.42201E-07	0.000959	5.06
2:36:11 PM	35.7619130	-120.9010177	0.62416313	-2.11012083	-8.37758E-08	-2.77507E-07	1.44316E-14	2.40263E-07	0.000951	5.02
2:36:12 PM	35.7619083	-120.9010335	0.62416305	-2.11012110	-8.20305E-08	-2.75762E-07	1.42003E-14	2.3833E-07	0.000944	4.98
2:36:13 PM	35.7619038	-120.9010495	0.62416297	-2.11012138	-7.85398E-08	-2.79253E-07	1.4379E-14	2.39825E-07	0.000949	5.01
2:36:14 PM	35.7618993	-120.9010655	0.62416289	-2.11012166	-7.85398E-08	-2.79253E-07	1.43791E-14	2.39825E-07	0.000949	5.01
2:36:15 PM	35.7618950	-120.9010817	0.62416281	-2.11012194	-7.50492E-08	-2.82743E-07	1.4568E-14	2.41396E-07	0.000956	5.05
2:36:16 PM	35.7618907	-120.9010980	0.62416274	-2.11012223	-7.50492E-08	-2.84489E-07	1.47309E-14	2.42742E-07	0.000961	5.07
2:36:17 PM	35.7618872	-120.9011140	0.62416268	-2.11012251	-6.10865E-08	-2.79253E-07	1.37698E-14	2.3469E-07	0.000929	4.91
2:36:18 PM	35.7618833	-120.9011300	0.62416261	-2.11012279	-6.80678E-08	-2.79253E-07	1.39952E-14	2.36603E-07	0.000937	4.95
2:36:19 PM	35.7618797	-120.9011462	0.62416255	-2.11012307	-6.28319E-08	-2.82743E-07	1.41468E-14	2.37881E-07	0.000942	4.97
2:36:20 PM	35.7618763	-120.9011620	0.62416249	-2.11012335	-5.93412E-08	-2.75762E-07	1.33984E-14	2.31503E-07	0.000917	4.84
2:36:21 PM	35.7618733	-120.9011778	0.62416244	-2.11012362	-5.23599E-08	-2.75762E-07	1.32034E-14	2.29812E-07	0.000910	4.80
2:36:22 PM	35.7618705	-120.9011940	0.62416239	-2.11012390	-4.88692E-08	-2.82743E-07	1.37569E-14	2.3458E-07	0.000929	4.90
2:36:23 PM	35.7618678	-120.9012100	0.62416234	-2.11012418	-4.71239E-08	-2.79253E-07	1.33921E-14	2.31448E-07	0.000916	4.84
2:36:24 PM	35.7618655	-120.9012263	0.62416230	-2.11012447	-4.01426E-08	-2.84489E-07	1.37257E-14	2.34313E-07	0.000928	4.90
2:36:25 PM	35.7618635	-120.9012423	0.62416226	-2.11012475	-3.49066E-08	-2.79253E-07	1.31416E-14	2.29273E-07	0.000908	4.79
2:36:26 PM	35.7618615	-120.9012588	0.62416223	-2.11012504	-3.49066E-08	-2.87979E-07	1.39564E-14	2.36274E-07	0.000935	4.94
2:36:27 PM	35.7618598	-120.9012753	0.62416220	-2.11012532	-2.96706E-08	-2.87979E-07	1.38719E-14	2.35558E-07	0.000933	4.92
2:36:28 PM	35.7618585	-120.9012918	0.62416218	-2.11012561	-2.26893E-08	-2.87979E-07	1.37805E-14	2.34781E-07	0.000929	4.91
2:36:29 PM	35.7618573	-120.9013085	0.62416216	-2.11012590	-2.0944E-08	-2.9147E-07	1.40944E-14	2.3744E-07	0.000940	4.96
2:36:30 PM	35.7618563	-120.9013250	0.62416214	-2.11012619	-1.74533E-08	-2.87979E-07	1.37279E-14	2.34333E-07	0.000928	4.90
2:36:31 PM	35.7618555	-120.9013417	0.62416213	-2.11012648	-1.39626E-08	-2.9147E-07	1.40335E-14	2.36926E-07	0.000938	4.95
2:36:32 PM	35.7618550	-120.9013583	0.62416212	-2.11012677	-8.72665E-09	-2.89725E-07	1.38368E-14	2.3526E-07	0.000931	4.92
2:36:33 PM	35.7618548	-120.9013752	0.62416211	-2.11012707	-3.49066E-09	-2.94961E-07	1.43248E-14	2.39372E-07	0.000948	5.00
2:36:34 PM	35.7618548	-120.9013922	0.62416211	-2.11012736	0	-2.96706E-07	1.44917E-14	2.40763E-07	0.000953	5.03
2:36:35 PM	35.7618552	-120.9014092	0.62416212	-2.11012766	6.98132E-09	-2.96706E-07	1.45039E-14	2.40864E-07	0.000954	5.03
2:36:36 PM	35.7618557	-120.9014262	0.62416213	-2.11012796	8.72665E-09	-2.96706E-07	1.45107E-14	2.40921E-07	0.000954	5.04
2:36:37 PM	35.7618567	-120.9014430	0.62416215	-2.11012825	1.74533E-08	-2.93215E-07	1.42289E-14	2.3857E-07	0.000944	4.99
2:36:38 PM	35.7618585	-120.9014597	0.62416218	-2.11012854	3.14159E-08	-2.9147E-07	1.42315E-14	2.38592E-07	0.000945	4.99
2:36:39 PM	35.7618607	-120.9014762	0.62416222	-2.11012883	3.83972E-08	-2.87979E-07	1.40204E-14	2.36815E-07	0.000938	4.95
2:36:40 PM	35.7618633	-120.9014928	0.62416226	-2.11012912	4.53786E-08	-2.89725E-07	1.43326E-14	2.39437E-07	0.000948	5.01
2:36:41 PM	35.7618663	-120.9015088	0.62416231	-2.11012940	5.23599E-08	-2.79253E-07	1.35223E-14	2.32571E-07	0.000921	4.86
2:36:42 PM	35.7618700	-120.9015248	0.62416238	-2.11012968	6.45772E-08	-2.79253E-07	1.38795E-14	2.35622E-07	0.000933	4.93
2:36:43 PM	35.7618740	-120.9015407	0.62416245	-2.11012996	6.98132E-08	-2.77507E-07	1.38954E-14	2.35758E-07	0.000933	4.93
2:36:44 PM	35.7618785	-120.9015565	0.62416253	-2.11013023	7.85398E-08	-2.75762E-07	1.40601E-14	2.37151E-07	0.000939	4.96
2:36:45 PM	35.7618835	-120.9015722	0.62416261	-2.11013051	8.72665E-08	-2.74017E-07	1.42639E-14	2.38863E-07	0.000946	4.99
2:36:46 PM	35.7618885	-120.9015875	0.62416270	-2.11013077	8.72665E-08	-2.67035E-07	1.36421E-14	2.33599E-07	0.000925	4.88
2:36:47 PM	35.7618940	-120.9016030	0.62416280	-2.11013104	9.59931E-08	-2.70526E-07	1.43508E-14	2.3959E-07	0.000949	5.01
2:36:48 PM	35.7619000	-120.9016178	0.62416290	-2.11013130	1.0472E-07	-2.58309E-07	1.37252E-14	2.34309E-07	0.000928	4.90
2:36:49 PM	35.7619065	-120.9016325	0.62416302	-2.11013156	1.13446E-07	-2.56563E-07	1.40532E-14	2.37092E-07	0.000939	4.96
2:36:50 PM	35.7619133	-120.9016463	0.62416313	-2.11013180	1.18682E-07	-2.40855E-07	1.30708E-14	2.28656E-07	0.000905	4.78
2:36:51 PM	35.7619207	-120.9016598	0.62416326	-2.11013203	1.29154E-07	-2.35619E-07	1.3309E-14	2.30729E-07	0.000913	4.82
2:36:52 PM	35.7619283	-120.9016725	0.62416340	-2.11013226	1.32645E-07	-2.21657E-07	1.24864E-14	2.23485E-07	0.000885	4.67
2:36:53 PM	35.7619368	-120.9016852	0.62416354	-2.11013248	1.48353E-07	-2.21657E-07	1.35899E-14	2.33152E-07	0.000923	4.87
2:36:54 PM	35.7619458	-120.9016973	0.62416370	-2.11013269	1.5708E-07	-2.11185E-07	1.35101E-14	2.32466E-07	0.000920	4.86
2:36:55 PM	35.7619555	-120.9017083	0.62416387	-2.11013288	1.69297E-07	-1.91986E-07	1.32328E-14	2.30068E-07	0.000911	4.81
2:36:56 PM	35.7619660	-120.9017187	0.62416405	-2.11013306	1.8326E-07	-1.81514E-07	1.38196E-14	2.35114E-07	0.000931	4.91
2:36:57 PM	35.7619772	-120.9017275	0.62416425	-2.11013322	1.95477E-07	-1.53589E-07	1.3436E-14	2.31827E-07	0.000918	4.85
2:36:58 PM	35.7619888	-120.9017353	0.62416445	-2.11013335	2.02458E-07	-1.36136E-07	1.32981E-14	2.30635E-07	0.000913	4.82
2:36:59 PM	35.7620012	-120.9017420	0.62416467	-2.11013347	2.16421E-07	-1.16937E-07	1.39605E-14	2.36309E-07	0.000936	4.94
2:37:00 PM	35.7620138	-120.9017485	0.62416489	-2.11013358	2.19911E-07	-1.13446E-07	1.42089E-14	2.38402E-07	0.000944	4.98
2:37:01 PM	35.7620267	-120.9017537	0.62416511	-2.11013367	2.25147E-07	-9.07571E-08	1.40287E-14	2.36886E-07	0.000938	4.95
2:37:02 PM	35.7620395	-120.9017572	0.62416534	-2.11013373	2.23402E-07	-6.10865E-08	1.30914E-14	2.28835E-07	0.000906	4.78
2:37:03 PM	35.7620523	-120.9017588	0.62416556	-2.11013376	2.23402E-07	-2.79253E-08	1.26055E-14	2.24548E-07	0.000889	4.69
2:37:04 PM	35.7620652	-120.9017593	0.62416579	-2.11013377	2.25147E-07	-8.72665E-09	1.26854E-14	2.25259E-07	0.000892	4.71
2:37:05 PM	35.7620778	-120.9017585	0.62416600	-2.11013376	2.19911E-07	1.39626E-08	1.21224E-14	2.20203E-07	0.000872	4.60
2:37:06 PM	35.7620903	-120.9017560	0.62416622	-2.11013371	2.18166E-07	4.36332E-08	1.22125E-14	2.21021E-07	0.000875	4.62
2:37:07 PM	35.7621028	-120.9017517	0.62416644	-2.11013364	2.18166E-07	7.50492E-08	1.28263E-14	2.26506E-07	0.000897	4.73
2:37:08 PM	35.7621147	-120.9017465	0.62416665	-2.11013355	2.07694E-07	9.07571E-08	1.21401E-14	2.20364E-07	0.000872	4.61
2:37:09 PM	35.7621258	-120.9017403	0.62416684	-2.11013344	1.93732E-07	1.0821E-07	1.13105E-14	2.12702E-07	0.000842	4.45
2:37:10 PM	35.7621370	-120.9017327	0.62416704	-2.11013331	1.95477E-07	1.32645E-07	1.24491E-14	2.23151E-07	0.000883	4.66
2:37:11 PM	35.7621473	-120.9017237	0.62416722	-2.11013315	1.79769E-07	1.5708E-07	1.21409E-14	2.20371E-07	0.000872	4.61
2:37:12 PM	35.7621563	-120.9017132	0.62416738	-2.11013297	1.5708E-07	1.8326E-07	1.16969E-14	2.16304E-07	0.000856	4.52
2:37:13 PM	35.7621643	-120.9017012	0.62416751	-2.11013276	1.39626E-07	2.0944E-07	1.20946E-14	2.19951E-07	0.000871	4.60
2:37:14 PM	35.7621718	-120.9016877	0.62416765	-2.11013252	1.309E-07	2.35619E-07	1.34224E-14	2.3171E-07	0.000917	4.84
2:37:15 PM	35.7621778	-120.9016738	0.62416775	-2.11013228	1.0472E-07	2.42601E-07	1.24299E-14	2.22979E-07	0.000883	4.66
2:37:16 PM	35.7621822	-120.9016595	0.62416783	-2.11013203	7.67945E-08	2.49582E-07	1.17283E-14	2.16594E-07	0.000857	4.53
2:37:17 PM	35.7621860	-120.9016447	0.62416789	-2.11013177	6.63225E-08	2.58309E-07	1.20832E-14	2.19847E-07	0.000870	4.60
2:37:18 PM	35.7621882	-120.9016305	0.62416793	-2.11013152	3.83972E-08	2.47837E-07	1.04796E-14	2.0474E-07	0.000811	4.28
2:37:19 PM	35.7621870	-120.9016180	0.62416791	-2.11013131	-2.0944E-08	2.18166E-07	7.94464E-15	1.78265E-07	0.000706	3.73
2:37:20 PM	35.7621830	-120.9016088	0.62416784	-2.11013114	-6.98132E-08	1.6057E-07	5.46265E-15	1.47819E-07	0.000585	3.09
2:37:21 PM	35.7621763	-120.9016047	0.62416772	-2.11013107	-1.16937E-07	7.15585E-08	4.26149E-15	1.3056E-07	0.000517	2.73
2:37:22 PM	35.7621683	-120.9016047	0.62416758	-2.11013107	-1.39626E-07	0	4.87388E-15	1.39626E-07	0.000553	2.92
2:37:23 PM	35.7621608	-120.9016063	0.62416745	-2.11013110	-1.309E-07	-2.79253E-08	4.41205E-15	1.32847E-07	0.000526	2.78
2:37:24 PM	35.7621552	-120.9016068	0.62416736	-2.11013111	-9.77384E-08	-8.72665E-09	2.40074E-15	9.79946E-08	0.000388	2.05
2:37:25 PM	35.7621520	-120.9016062	0.62416730	-2.11013110	-5.58505E-08	1.0472E-08	7.97872E-16	5.64933E-08	0.000224	1.18
2:37:26 PM	35.7621495	-120.9016050	0.62416726	-2.11013108	-4.36332E-08	2.0944E-08	5.48172E-16	4.68261E-08	0.000185	0.98
2:37:27 PM	35.7621487	-120.9016042	0.62416724	-2.11013106	-1.39626E-08	1.39626E-08	8.08309E-17	1.79812E-08	0.000071	0.38

Example Calculations

Using the Haversine Formula:

$$d = 2 \cdot r \cdot \arcsin\left(\sqrt{\sin^2\left(\frac{\varphi_2 - \varphi_1}{2}\right) + \cos(\varphi_1)\cos(\varphi_2)\sin^2\left(\frac{\lambda_2 - \lambda_1}{2}\right)}\right)$$

where

$r \equiv$ radius of Earth, in feet

$\left.\begin{array}{l} \varphi_1 \equiv \text{latitude of position 1} \\ \varphi_2 \equiv \text{latitude of position 2} \\ \lambda_1 \equiv \text{longitude of position 1} \\ \lambda_2 = \text{longitude of position 2} \end{array}\right\}$ in radians

$d \equiv$ distance between points

Let $\Delta\varphi = \varphi_2 - \varphi_1$

$\Delta\lambda = \lambda_2 - \lambda_1$

$a = \sin^2\left(\frac{\Delta\varphi}{2}\right) + \cos(\varphi_1)\cos(\varphi_2)\sin^2\left(\frac{\Delta\lambda}{2}\right)$

$c = 2 \cdot \arcsin(\sqrt{a})$

$\therefore d = r \cdot c$

For 35.7621755, -120.9015973 and 35.7621738, -120.9015997:

$\varphi_1 = \frac{35.7621755 \cdot \pi}{180}$ $\qquad$ $\varphi_2 = \frac{35.7621738 \cdot \pi}{180}$

$= 0.62416771$ $\qquad$ $= 0.62416768$

$\lambda_1 = \frac{-120.9015973 \cdot \pi}{180}$ $\qquad$ $\lambda_2 = \frac{-120.9015997 \cdot \pi}{180}$

$= -2.110130944$ $\qquad$ $= -2.110130986$

$\therefore \Delta\varphi = 0.62416788 - 0.62416771$

$= -2.96706 \times 10^{-8}$

$\Delta\lambda = -2.110130986 - -2.110130944$

$= -4.18879 \times 10^{-8}$

Example Calculations

$$a = \sin^2\left(\frac{-2.96706\times10^{-8}}{2}\right) + \cos(.62416771)\cos(.62416768) \cdot \sin^2\left(\frac{-4.188790\times10^{-8}}{2}\right)$$

$$= 5.09\times10^{-16}$$

$$c = 2\cdot\arcsin\left(\sqrt{5.09\times10^{-16}}\right)$$
$$= 4.51\times10^{-8}$$

$$r = 3959.0 \text{ miles} \cdot \frac{5280 \text{ ft}}{\text{mile}}$$
$$= 20903520 \text{ feet}$$

$$\therefore d = 4.51\times10^{-8} \cdot 20903520 \text{ feet}$$

$$\boxed{d = 0.94 \text{ feet}}$$

Z. Appendix Z: Uncertainty Calculations for Speed Test

1/3

Uncertainty Calculations

Haversine Formula

$$d = 2r \cdot \arcsin\left(\sqrt{\sin^2\left(\frac{\varphi_2-\varphi_1}{2}\right) + \cos(\varphi_1)\cos(\varphi_2)\cdot\sin^2\left(\frac{\lambda_2-\lambda_1}{2}\right)}\right)$$

$$U_d = \pm\left[U_{d,\varphi_1}{}^2 + U_{d,\varphi_2}{}^2 + U_{d,\lambda_1}{}^2 + U_{d,\lambda_2}{}^2\right]^{1/2}$$

$$U_{d,\varphi_1} = \pm\frac{\partial d}{\partial \varphi_1}\cdot U_{\varphi_1}$$

$$U_{d,\varphi_2} = \pm\frac{\partial d}{\partial \varphi_2}\cdot U_{\varphi_2}$$

$$U_{d,\lambda_1} = \pm\frac{\partial d}{\partial \lambda_1}\cdot U_{\lambda_1}$$

$$U_{d,\lambda_2} = \pm\frac{\partial d}{\partial \lambda_2}\cdot U_{\lambda_2}$$

$$\frac{\partial d}{\partial \varphi_1} = 2r\cdot\frac{1}{\sqrt{1-\left[\sin^2\left(\frac{\varphi_2-\varphi_1}{2}\right)+\cos(\varphi_1)\cos(\varphi_2)\cdot\sin^2\left(\frac{\lambda_2-\lambda_1}{2}\right)\right]}}$$

$$\cdot\frac{1}{2}\left[\sin^2\left(\frac{\varphi_2-\varphi_1}{2}\right)+\cos(\varphi_1)\cos(\varphi_2)\cdot\sin^2\left(\frac{\lambda_2-\lambda_1}{2}\right)\right]^{-1/2}$$

$$\cdot\left(2\cdot\sin\left(\frac{\varphi_2-\varphi_1}{2}\right)\cdot\cos\left(\frac{\varphi_2-\varphi_1}{2}\right)\cdot\frac{-1}{2} + -\sin(\varphi_1)\cos(\varphi_2)\cdot\sin^2\left(\frac{\lambda_2-\lambda_1}{2}\right)\right]$$

Let $\Delta\varphi = \varphi_2 - \varphi_1$

$\Delta\lambda = \lambda_2 - \lambda_1$

$a = \sin^2\left(\frac{\Delta\varphi}{2}\right) + \cos(\varphi_1)\cos(\varphi_2)\,\sin^2\left(\frac{\Delta\lambda}{2}\right)$

$$\therefore \frac{\partial d}{\partial \varphi_1} = \frac{2r}{\sqrt{1-a}}\cdot\frac{1}{2\sqrt{a}}\cdot\left[-\sin\left(\frac{\Delta\varphi}{2}\right)\cdot\cos\left(\frac{\Delta\varphi}{2}\right) - \sin(\varphi_1)\cos(\varphi_2)\cdot\sin^2\left(\frac{\Delta\lambda}{2}\right)\right]$$

Uncertainty Calculations

$$U_{\varphi_1} = \frac{.0000001 \cdot \pi}{180}$$

Partials will be very similiar

$$\frac{\partial d}{\partial \varphi_2} = \frac{2r}{\sqrt{1-a}} \cdot \frac{1}{2\sqrt{a}} \cdot \left[\sin\left(\frac{\Delta\varphi}{2}\right) \cdot \cos\left(\frac{\Delta\varphi}{2}\right) - \cos(\varphi_1)\sin(\varphi_2) \cdot \sin^2\left(\frac{\Delta\lambda}{2}\right)\right]$$

$$U_{\varphi_2} = \frac{.0000001 \cdot \pi}{180}$$

$$\frac{\partial d}{\partial \lambda_1} = \frac{2r}{\sqrt{1-a}} \cdot \frac{1}{2\sqrt{a}} \cdot \left[\cos(\varphi_1)\cos(\varphi_2) \cdot \cancel{2} \cdot \sin\left(\frac{\Delta\lambda}{2}\right) \cdot \cos\left(\frac{\Delta\lambda}{2}\right) \cdot \frac{-1}{\cancel{2}}\right]$$

$$U_{\lambda_1} = \frac{.0000001 \cdot \pi}{180}$$

$$\frac{\partial d}{\partial \lambda_2} = \frac{2r}{\sqrt{1-a}} \cdot \frac{1}{2\sqrt{a}} \cdot \left[\cos(\varphi_1)\cos(\varphi_2) \cancel{2}\sin\left(\frac{\Delta\lambda}{2}\right) \cdot \cos\left(\frac{\Delta\lambda}{2}\right) \cdot \frac{1}{\cancel{2}}\right]$$

$$U_{\lambda_2} = \frac{.0000001 \cdot \pi}{180}$$

For Position 1: 35.7621755, -120.9015973
Position 2: 35.7621738, -120.9015997

Converting to radians

$$\varphi_1 = \frac{35.7621755 \cdot \pi}{180} = .62416771 \qquad \varphi_2 = \frac{35.7621738 \cdot \pi}{180} = .62416768$$

$$\lambda_1 = \frac{-120.9015973 \cdot \pi}{180} = -2.110130944 \qquad \lambda_2 = \frac{-120.9015997 \cdot \pi}{180} = -2.110130986$$

Uncertainty Calculations

$$U_{\varphi_1} = \frac{.0000001 \cdot \pi}{180}$$

Partials will be very similiar

$$\frac{\partial d}{\partial \varphi_2} = \frac{2r}{\sqrt{1-a}} \cdot \frac{1}{2\sqrt{a}} \cdot \left[\sin\left(\frac{\Delta\varphi}{2}\right) \cdot \cos\left(\frac{\Delta\varphi}{2}\right) - \cos(\varphi_1)\sin(\varphi_2) \cdot \sin^2\left(\frac{\Delta\lambda}{2}\right) \right]$$

$$U_{\varphi_2} = \frac{.0000001 \cdot \pi}{180}$$

$$\frac{\partial d}{\partial \lambda_1} = \frac{2r}{\sqrt{1-a}} \cdot \frac{1}{2\sqrt{a}} \cdot \left[\cos(\varphi_1)\cos(\varphi_2) \cdot \cancel{2} \cdot \sin\left(\frac{\Delta\lambda}{2}\right) \cdot \cos\left(\frac{\Delta\lambda}{2}\right) \cdot \frac{-1}{\cancel{2}} \right]$$

$$U_{\lambda_1} = \frac{.0000001 \cdot \pi}{180}$$

$$\frac{\partial d}{\partial \lambda_2} = \frac{2r}{\sqrt{1-a}} \cdot \frac{1}{2\sqrt{a}} \cdot \left[\cos(\varphi_1)\cos(\varphi_2) \cancel{2}\sin\left(\frac{\Delta\lambda}{2}\right) \cdot \cos\left(\frac{\Delta\lambda}{2}\right) \cdot \frac{1}{\cancel{2}} \right]$$

$$U_{\lambda_2} = \frac{.0000001 \cdot \pi}{180}$$

For Position 1: 35.7621755, -120.9015973
Position 2: 35.7621738, -120.9015997

Converting to radians

$$\varphi_1 = \frac{35.7621755}{180} \cdot \pi \qquad \varphi_2 = \frac{35.7621738 \cdot \pi}{180}$$

$$= .62416771 \qquad = .62416768$$

$$\lambda_1 = \frac{-120.9015973 \cdot \pi}{180} \qquad \lambda_2 = \frac{-120.9015997 \cdot \pi}{180}$$

$$= -2.110130944 \qquad = -2.110130986$$

AA. Appendix AA: Assembly and User Manual

Assembly and User Manual

Unmanned Research Raft

Presented by: Sea Cubed

May 2021
Version 1.0

In partnership with:

Lawrence Livermore National Laboratory

Table of Contents

1.0 General

This assembly and user manual outlines information regarding proper operation of the raft and includes important safety information to minimize any risks or hazards associated with the raft. Please be sure to read the entire manual before assembling or operating the raft.

1.1 Safety

To ensure the correct and safe use of the raft, only qualified individuals should be allowed to handle the raft. Handling of the raft includes, but is not limited to, transportation, deployment, field operation, retrieval, storage, and maintenance. Users should always wear proper personal protective equipment (PPE), consider potential hazards and practice upmost safety when handling any part of the raft. Further sections will highlight potential safety issues and recommend risk reduction methods to ensure safe operation of the raft.

This is a specialized watercraft for specific uses. It should not be used for recreational watercraft activities, nor is it intended to support the weight of a person. Any and all users who deploy, retrieve, store, maintain, modify, alter, or otherwise interact with the raft in a meaningful capacity should have knowledge of its capabilities, uses, and operating modes and conditions. This is necessary to prevent unintentional misuse of the raft and the components with which it interacts.

2.0 System Overview

The raft consists of two subassemblies—the frame and the pontoons. The frame subassembly consists of the frame, motor attachments, payload box, battery, and light pole. The pontoon subassembly contains the two rubber pontoons. Figure 1 shows the entire raft system.

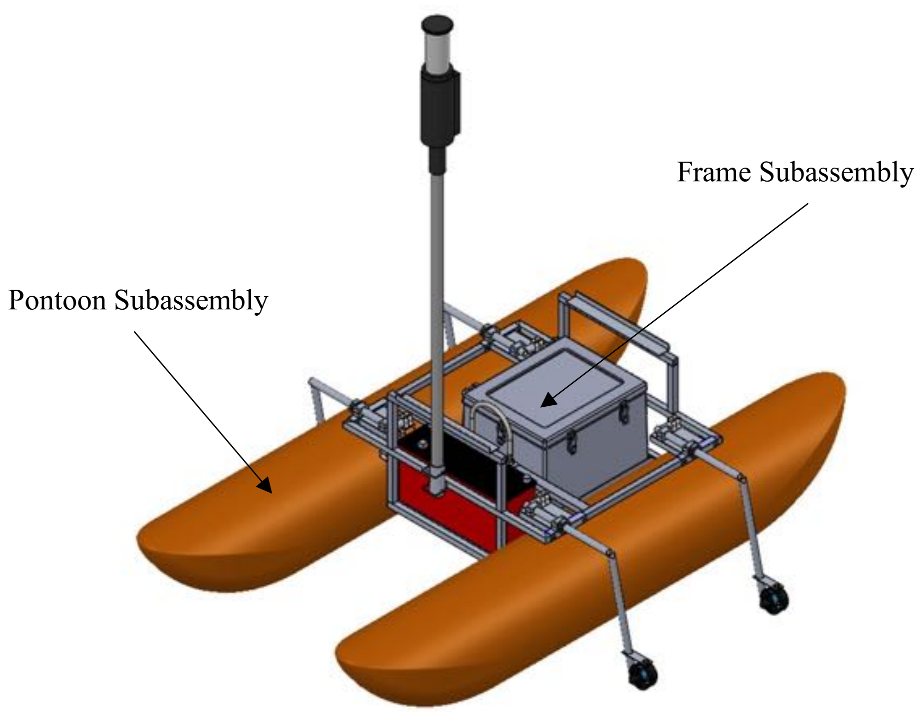


Figure 1: Raft Verification Prototype CAD Model.

The frame is the structure that accepts the motor attachments and supports the payload box, battery, and light pole. The battery is the main power source for all the electronics within the payload box, which in turn are responsible for the operation of the entire raft, including power distribution, data collection, and motor control. Assembly and operation of the components are covered in the Assembly chapter located in the full report. The pontoons are responsible for supporting the frame and keeping the entire raft afloat. They are two custom-made Maravia pontoons with a diameter of 16 inches and a length of 9 feet.

3.0 Assembly

Assembly of the raft will first include assembling the motor attachment and electronics/wiring of the payload box. Once these subsystems are complete, select components are installed onto the frame before securing the frame onto the pontoons. Lastly, the motor attachments should be installed and wired to the payload box.

3.1 Subsystem Assembly

Before the final assembly of the raft, the user must first ensure the motor attachment and the payload box are properly assembled. This means using fasteners to install the clips and thruster onto the motor attachment and connecting/routing wires inside and outside of the payload box.

3.1.1 *Motor Attachment*

Assembly of the motor attachment includes fastening the clips and thruster into their specified locations. Below are steps to complete the assembly of the motor attachment.

1. Install the clips for the motor mount using the #6-32 x 3/8 machine screws and the respective #6-32 nuts, in the configuration shown in Figure 2.

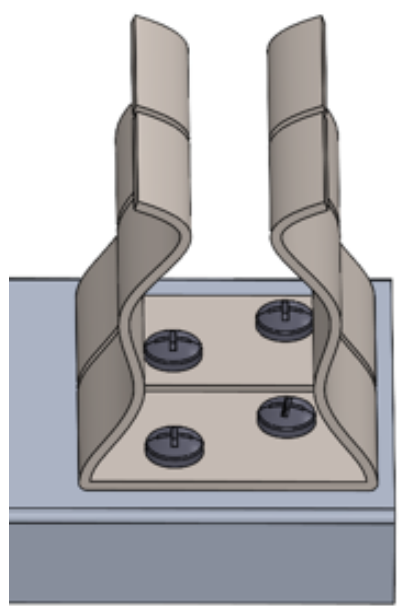


Figure 2: Motor Mount Clips.

2. Install the thrusters onto the motor arm plate at the orientation of the users choosing using the M3 x 0.5 screws and the M3 split lock washers. Make sure the bulbous part of the thruster is facing the forward direction, as indicated in Figure 3.

   Warning: Only install the thrusters when the power is disconnected to prevent any sudden starts that may lead to an injury.

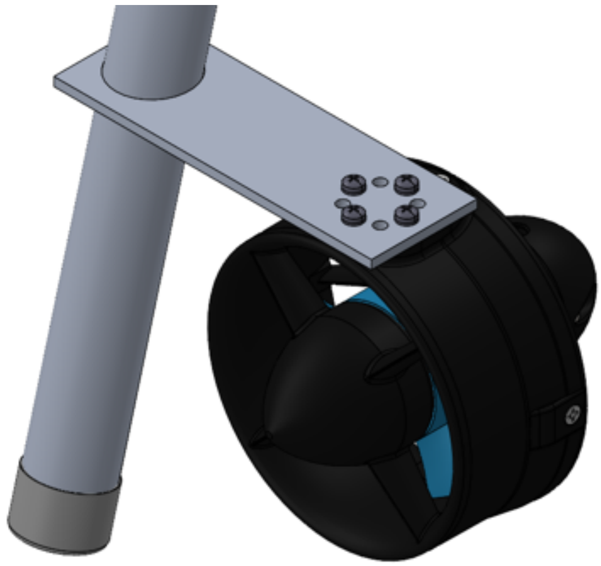


Figure 3: Thruster Orientation, with the front of the raft to the top right.

3.1.2 *Payload Box*

Assembly of the payload box includes fastening the electronics mounting panel and connecting wires within the box.

1. Before placing the electronics panel in the payload box, ensure that all components are attached and securely fastened to the panel.

2. Lower the panel into the box, electronics side up, so that all four mounting holes slide over the mounting studs within the box.

3. Make sure the panel lies flat within the box, then secure it by tightening the 3/8 - 16 nuts onto the studs. The payload box with the installed electronics panel is in Figure 4 with arrows pointing to the four nuts.

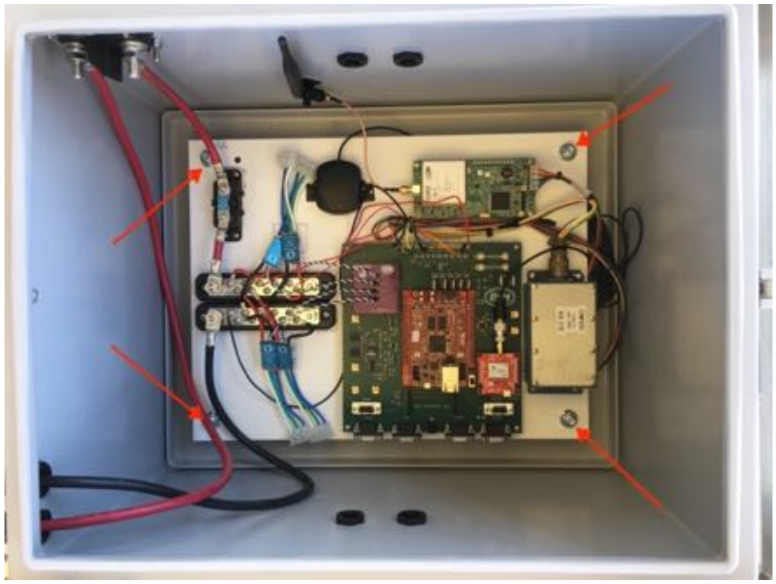


Figure 4: Electronics panel secured to payload box.

4. To connect the thruster cables, route all four cables through their corresponding cable glands and into the box. Then complete the cable wiring.
   a. Tighten the outside of the cable glands around the cable, until finger tight. The goal is to make a watertight connection between the gland and the cable, as shown in Figure 5.

Figure 5: Thruster cables tightened in cable gland

   b. Insert the exposed ends of the thruster cable wires into the terminal connector, making sure that the colored wires match their corresponding-colored wire from the ESCs.

c. Using a size 3.0 flat head screwdriver, tighten the screws on the terminal connector so that the thruster cable ends are secure, as in Figure 6.

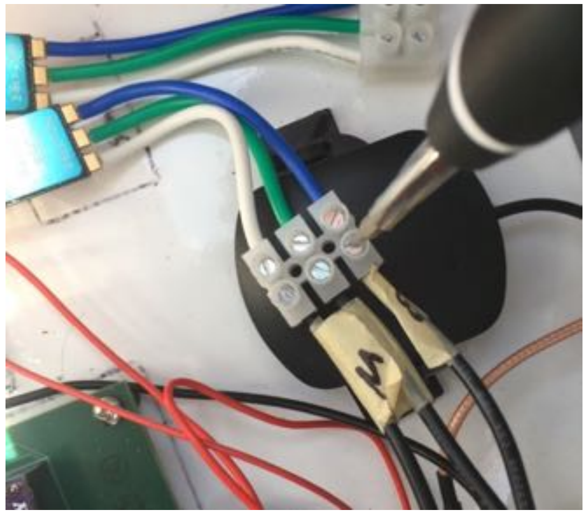


Figure 6: Size 3.0 flathead screwdriver securing cable connection.

5. Attach the black ground battery cable to the negative bus bar by removing the nut on the bus bar stud, sliding the cable lug over the stud, and tightening the nut back down. The completed attachment is shown in Figure 7.

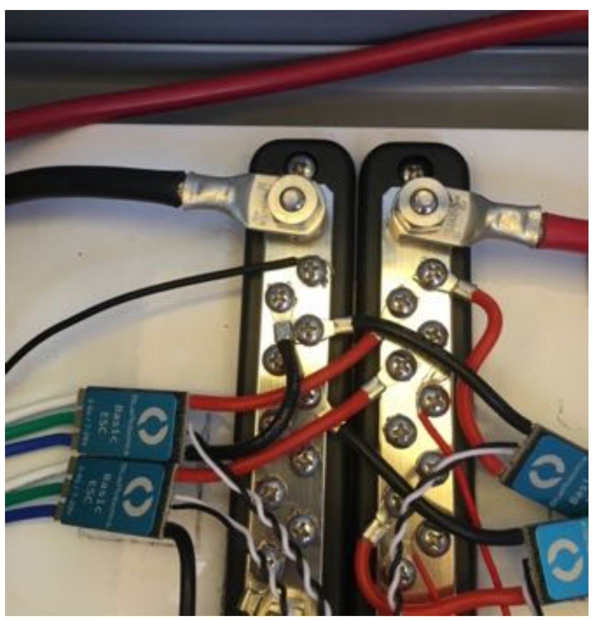


Figure 7: Power connection wiring to bus bars.

6. Attach the red positive battery cable running from the master switch to the fuse holder by removing the nut on the fuse holder and sliding the cable lug over the stud, as in Figure 8.

7. Install the 100A fuse by loosening both fuse holder nuts, sliding the fuse onto the holder studs, and then tightening the nuts down. Figure 8 shows this completed setup.

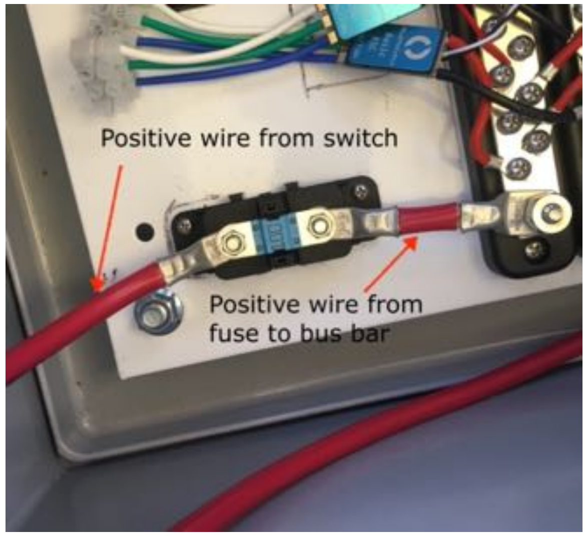


Figure 8: Wiring connection between power switch and bus bar.

8. Connect the FreeWave radio antenna to the FreeWave board by screwing the end of the antenna cable onto the connector on the board. Figure 9 shows the completion of this step.

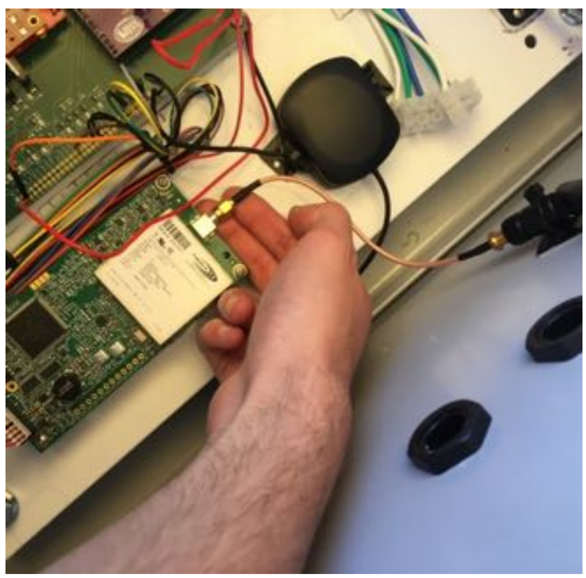


Figure 9: Attached radio antenna to the FreeWave board.

3.2 Final Assembly

The final assembly consists of attaching the frame and all its components to the pontoons. Doing so will complete the assembly of the raft and make the raft mission ready.

The following steps outline the recommended assembly for the frame and all its components:

1. Inflate the pontoons to 90% of their recommended pressure. The advised pressure rating will be provided by the manufacture when the pontoons are purchased.

2. Secure the payload box onto the lower frame deck using the four 7/16-20 bolts and their respective locking nuts shown in Figure 10.

Figure 10: Two of the four mounting bolts securing the payload box to the frame.

3. Secure the battery onto the frame using NRS 6-foot straps wrapped around the lower frame deck. The strap should encircle the center of the battery, shown in Figure 11.

   Warning: Use at least two people to place the battery into the frame. Never exceed a load of 50 lbs per person.

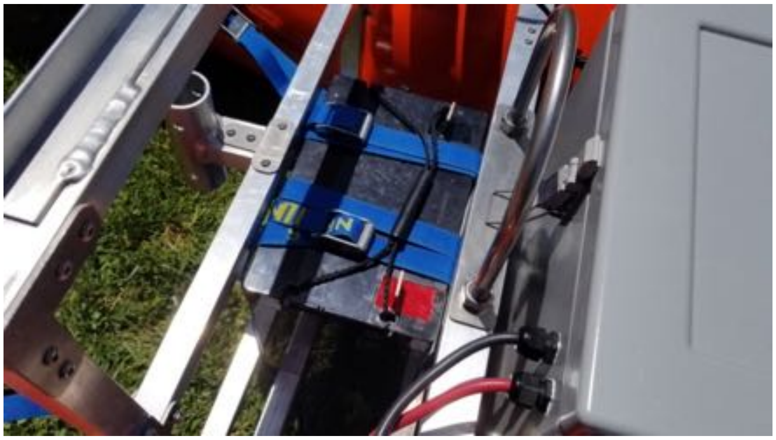


Figure 11: Battery securely strapped to the lower deck of the frame.

4. Lower the frame onto the pontoons and attach it to the pontoons using the 2- and 3-foot NRS straps. The straps will run through both the main deck and the d-rings to tightly secure each component to one another. Figure 12 shows the optimal strap configuration.

   Warning: Use at least use at least three people to place the frame onto the pontoons. Never exceed a load of 50 lbs per person.

Figure 12: NRS straps securing aluminum frame to the pontoons.

5. Install the four motor mounts onto their respective corners of the raft using two ¼-20 bolts and nuts on each mount.
6. Position the motor arm in the clip and onto the bottom holders and tighten down the top holders using the #8-32 shoulder screws. These secured holders are shown in Figure 13.

   Warning: Be cautious of pinch points when clipping in the arm.

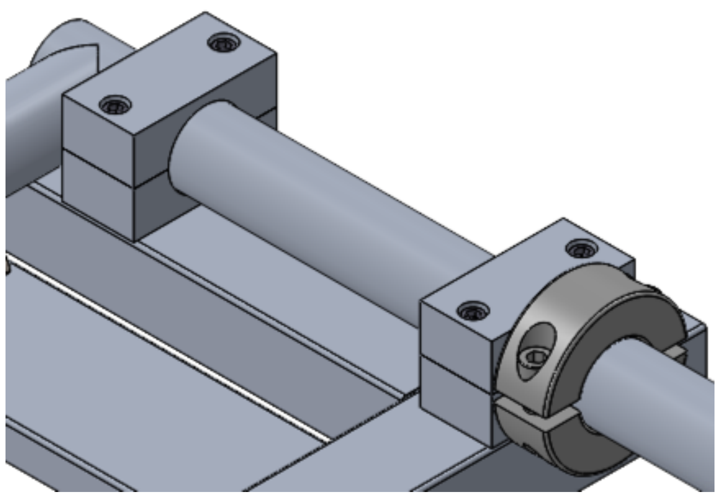


Figure 13: Motor arm secured in the holders.

7. Wire the thruster cable through along and through the arm and connect it to the payload box wire. See Figure 14 for reference.

Figure 14: Thruster cable routed through motor arm.

8. Zip-tie the thruster cable snug to the motor arm and bundle the excess wire.
9. Connect the positive and negative battery cables running out of the payload box to their respective battery terminals.
10. Install the light pole into the light pole holder using the lock pins. Figure 15 shows the light pole after completion of this step.

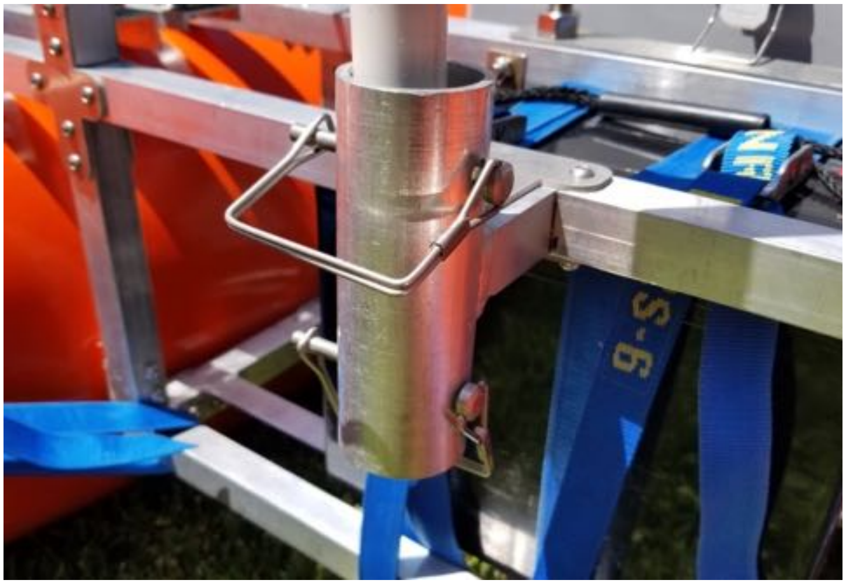


Figure 15: Light pole secured in holder using lock pins.

4.0 Field Operation

This section explains the proper use for each stage of field operation—pre-deployment, deployment, and post-retrieval. This encompasses the entirety of the raft's research mission from launching onto to retrieval from the ocean.

4.1 Pre-Deployment

The pre-deployment operation steps are as follows.

1. Loosen and remove the straps holding the stacked rafts together on deck.
2. Using a crane or at least 4 people, lift the raft off the stack of rafts and set it on the deck.

    Warning: Use at least use at least four people when lifting and transporting the raft. Never exceed a load of 50 lbs per person.
3. Ensure that the pontoons are fully inflated.
4. Remove the light pole from its attachment clips and install it in the light pole holder, fastening it with the two square wire pins.
5. Turn the main power switch to the ON position and ensure that all four payload box latches are fully closed.

    Warning: Failure to ensure the payload box is sealed may result in electronic failure, electric shock, or raft non-operation.
6. Attach the deployment crane hook to the lift point U-Bolt.
7. Using the crane, lift the raft at least a foot off the deck, so that the motor arms can be rotated into their fully locked positions. Then snap the motor arms into the clips

    Warning: Be aware of hanging structures around the raft, to prevent head wounds on sharp corners.

    Warning: While moving around the raft, take care to avoid tripping on structures on the floor and to avoid slipping on standing water.

    Warning: The clips and motor arms form a pinch point. Take care to ensure that appendages are not in the area when clipping the motor arms.
8. Using the crane, deploy the raft into the ocean.

4.2 During Mission

The mission operation steps are as follows.

1. Control the raft while on mission using the LIDSS control software interface. Training on how the software works and is operated in not covered in this user manual and further detail must be obtained through LLNL.

4.3 Post Deployment

1. After retrieving the raft from the water using a crane, gently lower the raft onto the deck, making sure that all four-motor arms release from their clips and rotate up.
    a. If motor arms do not initially release, manually release the arms before fully setting the raft down.
    b. Alternatively, the raft can be lowered directly on top of another raft. If using this option, align the underside of the lifted raft with the supports of the stationary raft before lowering the raft and detaching the crane hook. Then follow instructions but skip step 5.

Warning: Motor arms may pop out of the clips suddenly and without warning. Avoid motor arms to prevent bumps and cuts from sharp edges.

2. Release the crane hook from the lift point U bolt.
3. Turn the main power switch to the OFF position.
4. Remove the light pole from the holder by removing the two square wire pins and stow it on the frame using the light pole storage clips.
5. Using a crane or at least 4 people, lift the raft and place it on top of another raft, making sure that the frame of the raft aligns with the stacking supports of the raft below it.

   Warning: Use at least use at least four people when lifting and transporting the raft. Never exceed a load of 50 lbs per person.
6. Secure the stacked rafts to the deck using straps to ensure the stack is stable.

5.0 Maintenance and Repair

This section details the guidelines for storage and repair for the rafts. These are general guidelines, and the operating institution's care, storage, maintenance, and repair procedures take precedence over the guidelines listed in this manual.

5.1 Break Down and Storage

Break down and storage after use ensures that all components are clean and preventative measures are taken to ensure component longevity. The raft should be disassembled using the reverse procedure for the final assembly. Once broken down, fresh water should be used to wash all components after marine exposure. A cloth can be used in conjunction with running water in areas where necessary to clean the raft. The pontoons need to be further cleaned with 303 Aerospace Protectant. Wipe down the rubber after the cleaner is applied and let them dry. Lightly roll the pontoons up and store out of direct sunlight in a rodent safe location.

The battery should be charged to at least 40% and stored in a dry area at or below room temperature. If the battery will not be used for extended periods a trickle charger should be hooked up to the battery to maintain performance over the lifetime of the battery. The remainder of the components should be dried and inspected for damage or extensive wear. If any parts show symptoms of damage or extensive wear they should be replaced before the next use of the raft.

5.2 Parts

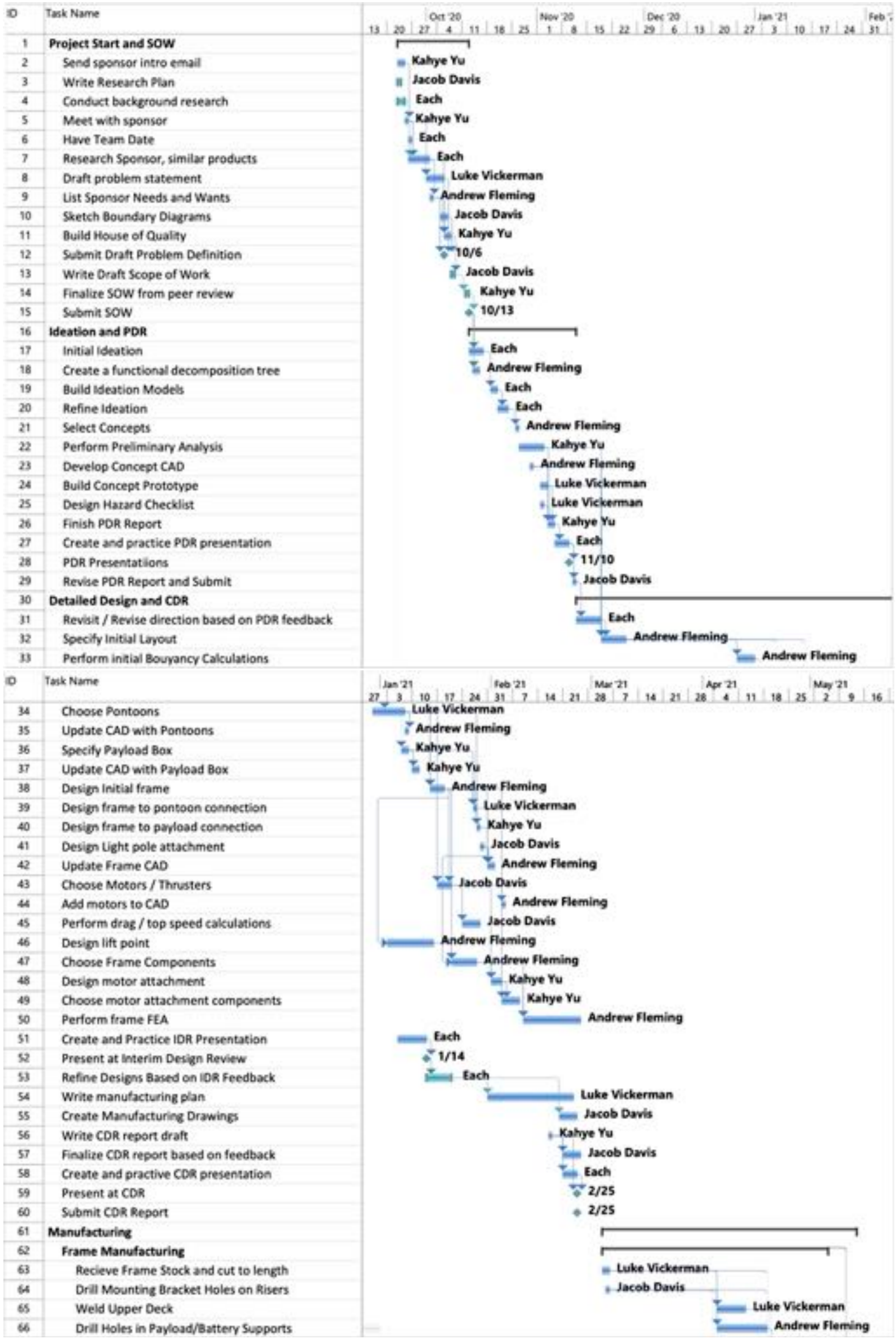
The readily available parts that can be used to quickly fix the raft are listed below in Table 1. Many of the larger components such as the pontoons, payload box, and frame cannot be quickly replaced as they are custom designs and are subject to manufacturing lead times.

Table 1: Readily available OTS components.

Part	Manufacturer	Product Number	Specifications
Motor Mount Mounting Bolts	Fastenal	172248	¼-20 x 1 5/8” Hex Bolt
Motor Mount Mounting Nuts	Fastenal	77860	¼-20 Ny-Lock Nut
Holder Socket Screw	Fastenal	79014	#8-32 x ¾” ASTM Hex Drive
Clip Screw	Fastenal	178569	#6-32 x 3/8” Phillips Drive Pan head
Clip Nut	Fastenal	77855	#6-32 Nylon Insert Lock Nut
Motor Arm Clip	Amarine Made	615200851446	Amarine Boat Spring Clip
Thruster Screw	Fastenal	QM2510008A20000	M3x0.5 8mm Pan Head Screw
Thruster Lock Washer	Fastenal	ML63300000A20000	M3 DIN 127 A2 Split Lock Washer
Thruster	Blue Robotics	T200-THRUSTER-R2-RP	Blue Robotics T200 Thruster
Thruster ESC	Blue Robotics	BESC30-R3	Blue Robotics Basic ESC
Thruster Cable	Blue Robotics	CAB-PUR-3-16AWG-R2	Thruster Cable, 3 Conductors, 16AWG
Fuse	Littelfuse Inc.	142.5631.6102	Auto Fuse 100A, 58VDC
Flash Pole Lock Pin	Fastenal	11104144	0.25” Dia x 2.5”L 18-8S/S Square Double Wire Snapper Pin
Payload Box Mounting Bolts	Fastenal	11540966	7/16”-20 x 1-¾" Hex Cap Screw
Payload Box Mounting Nuts	Fastenal	37306	7/16”-20 Lock Nut
Frame Straps	Northwestern River Supply	60027.01	Varying Sizes

These components can be purchased and taken along with the raft for quick fixes if failures occur while in use. A full list of all the components for the full raft can be found in the Bill of Materials for the specified raft design.

BB. Appendix BB: Gantt Chart




ID Task Name
Mar '21 Apr '21 May '21 Jun '21 Jul '21
28 7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18
67 Weld Lower Deck — Jacob Davis
68 Weld Mid Deck — Luke Vickerman
69 Waterjet components — Andrew Fleming
70 Drill Mounting Bracket Holes on Decks — Andrew Fleming
71 Cut Light Pole Mount Components — Andrew Fleming
72 Weld Misc Components to Deck — Jacob Davis
73 Bolt Decks together — Andrew Fleming
74 Install Lift Point — Andrew Fleming
75 Motor Mount Manufacturing
76 Submit Order for Motor Mount Components — Kahye Yu
77 Cut Motor Arm Components to length — Luke Vickerman
78 Notch Motor Arms — Andrew Fleming
79 Weld Motor Arms — Kahye Yu
80 Waterjet sheet stock — Andrew Fleming
81 Bend C channels — Jacob Davis
82 Weld Motor Mounts — Kahye Yu
83 Assemble Motor Attachment — Kahye Yu
84 Attach motors to motor arms — Kahye Yu
85 Electronic Manufacturing
86 Finalize Wiring Diagram — Andrew Fleming
87 Order payload box — Kahye Yu
88 Specify and order test battery — Andrew Fleming
89 Specify Fuse — Andrew Fleming
90 Specify Terminal Block — Andrew Fleming
91 Specify Waterproof Glands — Andrew Fleming
92 Order Electical Components — Andrew Fleming
93 Cut Connector Holes in Payload Box — Andrew Fleming
94 Install Wire Glands — Andrew Fleming
95 Recive Boards from LLNL — Kahye Yu
96 Solder wires between boards and connectors — Andrew Fleming
97 Splice motor mount wires — Jacob Davis
98 Assemble Raft Frame
99 Pontoons Arrive — 5/12
ID Task Name
Mar '21 Apr '21 May '21 Jun '21 Jul '21
28 7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18
100 Assemble Full Raft
101 Testing
102 Write Test Plans — All
103 Test Electronics Off Raft — Andrew Fleming
104 Perform Waterproof testing — Andrew
105 Seal Leaks Found — Andrew
106 Perform Speed Test — Jacob Davis
107 Analyze Speed Test Data — Jacob Davis
108 Perform Uncertainty Analysis — Jacob Davis
109 FDR and Expo
110 Create Expo Video
111 Creat Expo Webpage
112 Finalize FDR
113 Senior Project Expo Webpage Due — 6/3
114 Submit FDR to Sponsor — 6/8